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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms, in making these volumes thoroughly representative of the best and latest practice in the design and construction of steam and electrical machines and machine tools; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

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Introductory Note

THE Cyclopedia of Engineering is compiled from the most practical and comprehensive instruction papers of the American School of Correspondence. It is intended to furnish instruction to those who cannot take a correspondence course, in the same manner as the American School of Correspondence affords instruction to those who cannot attend a resident engineering college.

¶ The instruction papers forming the Cyclopedia have been prepared especially for home study by acknowledged authorities, and represent the most careful study of actual shop needs and conditions. Although primarily intended for correspondence study, they are in use as text books by Columbia University, Lehigh University, Iowa State College, the University of Maine, the U. S. Government in its School of Submarine Defense, the Westinghouse Companies in their Shop School, and for reference in the leading colleges, shops and public libraries.

¶ Years of experience in the shop, laboratory, and class-room have been required in the preparation of the various sections of the Cyclopedia. Each section has been tested by actual use for its practical value to the man who desires to know the latest and best practice in the shop or engine room.

¶ Numerous examples for practice are inserted at intervals; these, with the test questions, help the reader to fix in mind the essential points, thus combining the advantages of a text book with a reference work.

¶ Grateful acknowledgment is due to the corps of writers and collaborators, who have prepared the many sections of this work. The hearty co-operation of these men—engineers of wide practical experience and acknowledged ability — has alone made these volumes possible.

¶ The Cyclopedia has been compiled with the idea of making it a work thoroughly technical yet easily comprehended by the man who has but little time in which to acquaint himself with the fundamental branches of practical engineering. If, therefore, it should benefit any of the large number of workers who need, yet lack, technical training, the editors will feel that its mission has been accomplished.

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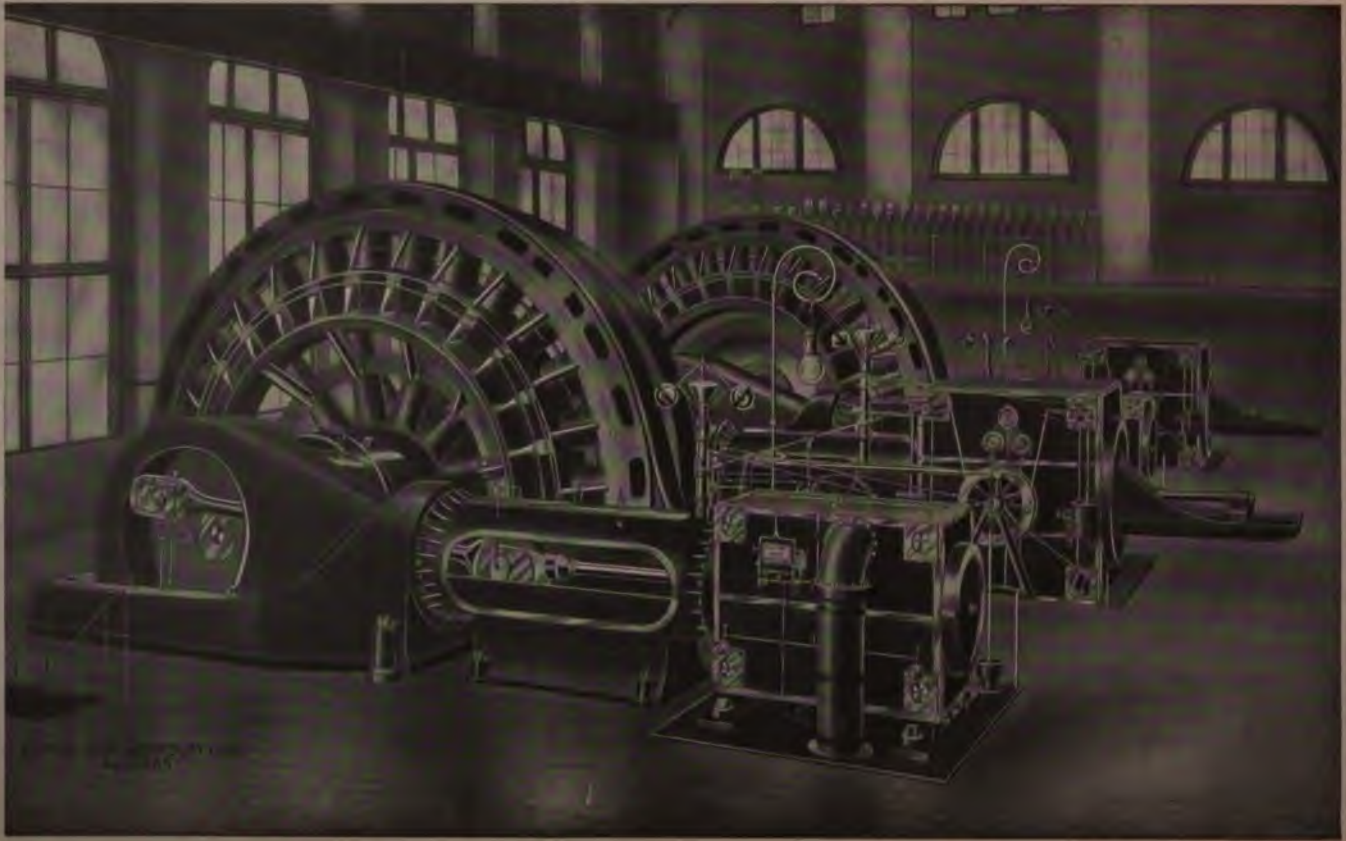

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THEORY OF DYNAMO-ELECTRIC MACHINERY.

THEORY OF THE GENERATOR.

Definition. A dynamo-electric machine is a machine in which mechanical energy is converted into electrical energy, or *vice versa*, by means of electro-magnetic induction.

The term *generator* is commonly applied to a machine which converts mechanical energy into electrical energy.

A *motor* serves to convert electrical energy into mechanical energy. The generator and motor are similar in construction, but the operation of one is the reverse of the other. The motor is separately considered in a following Instruction Paper.

The operation of a dynamo-electric machine depends upon the relation existing between magnetism and the electric current, and the fundamental principles will now be considered.

FUNDAMENTAL PRINCIPLES.

The Magnetic Field. The space surrounding a magnet is subject to its influence, and is called its magnetic field. This influence is exerted in certain definite directions, and its strength and direction are represented by lines of magnetic force. The strength of the field is indicated by the number of magnetic lines per unit area, and is called its density, or magnetic induction.

Fig. 1 represents the field of a permanent magnet, the lines of force passing outside the magnet from the north to the south pole in curved paths. The number of lines per unit of cross-section, and therefore the strength of the magnet, is greatest at the poles.

Magnetic Field of a Conducting Wire. Whenever a current of electricity passes through a conducting wire, the current creates a magnetic field, which surrounds the wire, as shown in Fig. 2. The magnetic lines of this field encircle the wire and have their greatest density near the same, gradually decreasing in effective strength as the distance from the wire increases. These magnetic lines of force represent a form of energy; and, in fact, a considerable portion of the energy of the current lies in the surrounding magnetic field.

The direction of the magnetic lines about the conductor always bears a definite relation to that of the current. When looking along the wire in the direction of the current, the direction of the lines of force will always be right-handed; that is, looking at the left-hand end of the conductor shown in Fig. 2, the current being from left to right, the lines of force have the same direction as the hands of a watch.

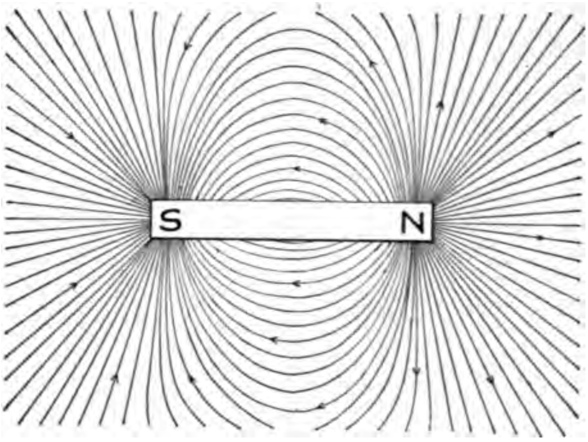

Fig. 1.

Field of a Solenoid and Electro-magnet. When a conductor is made in the form of a coil, and a current passed through the same, the lines of force, which would otherwise encircle each turn of the conductor, unite and form a strong magnetic field similar to that of a magnet.

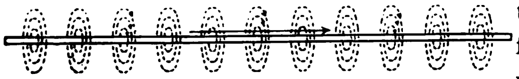

Fig. 2.

The magnetic field of a solenoid is represented by Fig. 3.

When the coil is supplied with a core of soft iron, the effective strength of the magnetic field is greatly increased. Such a combination is called an electro-magnet, and has the properties of a permanent magnet.

The end at which the lines of force leave the iron core and coil is called the north pole, and the end at which the lines enter the iron core and coil is called the south pole. When a person is facing the south pole, the direction of current in the coil is always in the same direction as the hands of a watch; and when facing the north pole, the current is in the opposite direction to the hands of a watch. This gives a very simple rule for determining the

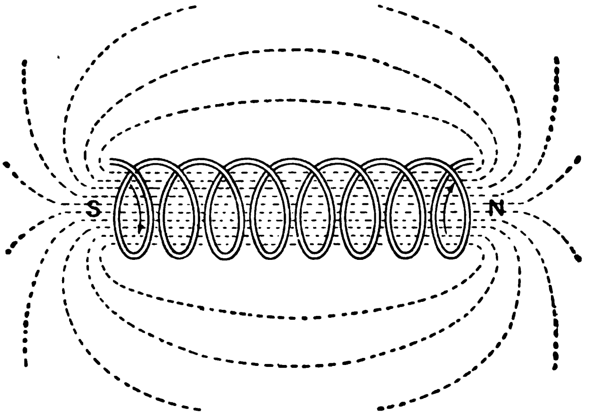

Fig. 8.

relation between the direction of current and polarity of the magnet.

Induced Currents. It would be supposed from the fact that a magnetic field is created by the passage of a current through a conductor, that the reverse action would also take place; that is, the creation of a magnetic field about a conductor would cause the production of a current, and such is found to be the case. The currents created in this manner are called *induced* currents, and are said to be produced by *induction*.

The subject of production of currents by induction is briefly considered in "Elements of Electricity," and the student will note the following facts :

1st. It is only by certain changes of relation between magnetic field and the conductor that the current is produced.

2nd. The change may be due to an increase or decrease in the strength of field about the conductor, and the current flows only while this change in field strength takes plnce.

3rd. The induced current flows in the opposite direction, when the field strength is increased to that in which it flows when the field strength is decreased.

4th. The change in field strength may be produced by the movement of a permanent magnet, solenoid or electro-magnet in the neighborhood of the conductor, — the source of the field is immaterial.

5th. Relative movement only is necessary, and hence it is immaterial whether the conductor is moved through the field or the field moved across the conductor.

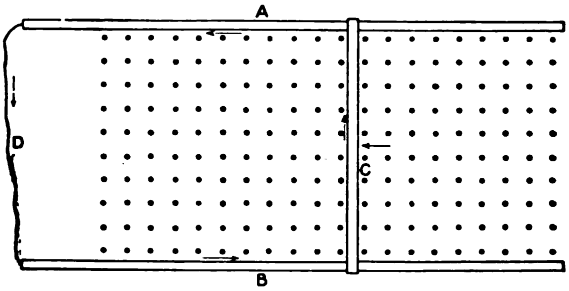

Fig. 4.

6th. The current flows through a closed circuit only as a result of the induced electro-motive force which is first created, and the strength of the current depends upon the value of the induced electro-motive force and resistance of the circuit, in accordance with Ohm's law.

Movement of Conductor Across the Field. We shall now consider more fully the production of E. M. F. and current by movement of a conductor *across* a magnetic field.

In Fig. 4 the dots represent the lines of force of a uniform field, their direction being upward through the paper. *C* represents a conductor which is movable on the rails *A* and *B*, the circuit through *B*, *C* and *A* being completed by the connecting wire *D*. Now when *C* slides along the rails, it cuts across the lines of force, an E. M. F. is induced, and a current flows, as indicated. The movement of *C* across the field causes a difference of potential between its ends, due to the fact that there is a continual cutting of lines of force about the conductor. If the slide *C* were moved endwise, however, no E. M. F. would be generated, as no lines would be cut, and during such movement there is no relative change of field with reference to the slide. The same would be true if the slide were moved vertically with reference to the paper. The moment there is any *cutting across* of the lines there is an E. M. F. induced. Such induced E. M. F. exists, however, only during the movement of the slide.

Value of Electromotive Force. The magnitude of the E. M. F. generated depends upon the *rate* at which the conductor cuts across the magnetic lines; that is, it depends upon the number of lines cut in a unit of time. If the conductor cuts across the field in a plane perpendicular to the lines of force, as indicated in Fig. 4, the E. M. F. would depend only upon the field area passed over in a unit of time and upon the density of the field. It therefore follows that the rate at which the lines are cut is determined by the *length* of the conductor, its *speed*, and the *strength* of magnetic field.

Taking, for example, the simple conditions of Fig. 4, let L represent the length of slide C, v its velocity, and B the field density, then

$$\text{E. M. F. varies as } L \times v \times B.$$

The electric and magnetic units are based upon the metric system, and have been so chosen that when a conductor cuts 100,000,000 lines of force per second, there exists a potential difference between its ends of 1 volt. The unit upon which the volt is based is the potential difference generated by moving a conductor 1 centimeter long at the rate of 1 centimeter per second across a field which has a strength of 1 line per square centimeter. This very small unit would be inconvenient for practical purposes, and so the volt was taken as 100,000,000 times this quantity. Hence it follows that

$$E = \frac{L \times v \times B}{100{,}000{,}000} = \frac{L \times v \times B}{10^8} = L \times v \times B \times 10^{-8}$$

where E = E. M. F. in volts induced in moving conductor;
L = length of conductor in centimeters;
v = velocity in centimeters per second;
B = number of lines of force per square centimeter.

Therefore, having given the length of conductor, the velocity and the field density, the E. M. F. generated may be computed readily; or if any three of the quantities are given, the fourth may be determined.

Example.— A conductor .6 meter long cuts across a uniform field having a density of 8,000 lines per square centimeter at the rate of 90 meters per minute. What is the voltage generated?

Solution.— Applying the preceding formula, $L = .6 \times 100 = 60$ cm., $v = \frac{90 \times 100}{60} = 150$ cm., and $B = 8{,}000$.

Substituting these values,

$$E = 60 \times 150 \times 8{,}000 \times 10^{-8} = .72 \text{ volt.}$$

Ans. .72 volt.

Example.—In order to generate a voltage of 1.1 by a conductor 1 meter long, when moving across a uniform field at the rate of 108 meters per minute, what must be the magnetic induction?

Solution.— The known quantities are

$$E = 1.1,\ L = 1 \times 100 = 100,\ v = \frac{108 \times 100}{60} = 180.$$

Substituting these values,

$$1.1 = 100 \times 180 \times B \times 10^{-8}$$

Or,

$$B = \frac{1.1 \times 100{,}000{,}000.}{18{,}000}$$

$$= 6{,}111 +$$

Ans. 6,111 + lines.

Direction of Induced Current. There is a definite relation between the direction of induced E. M. F., or current, the direction of motion and the direction of the lines of force. Referring to Fig. 4, and remembering that the lines of force are assumed to pass upward through the paper, and the slide C to move to the left, the direction of current along C will be that indicated by the arrow. The direction of lines of force, motion and current are all at right angles to each other. If C were moved to the right instead of to the left, the current would flow in the opposite direction to that indicated.

A simple rule for determining the direction of current is the "finger-rule" of Dr. Fleming. This is illustrated in Fig. 5. When the first three fingers of the *right* hand are placed so that they are at right angles to one another, then if the forefinger is pointed in the direction of the lines of force and the thumb in the direction of motion, the middle finger will indicate the direction of induced E. M. F., or current.

For example, if the lines of force were horizontal and passed from left to right and the conductor moved upward in a vertical plane across the lines, the direction of current in the conductor would be away from the observer. Also, if the direction of the lines of force of Fig. 4 were downward through the paper and the slide *C* were moved to the right, the current would still be in the same direction as that indicated. That is, if the direction of both the field and of motion be reversed, then the direction of current remains unchanged. Reversing *either* the field *or* the motion will reverse the direction of current.

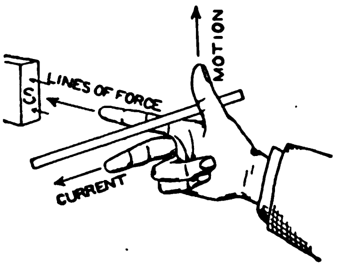

Fig. 5.

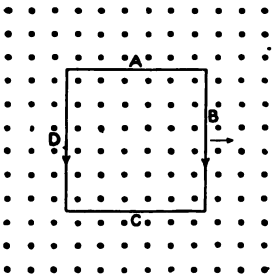

Fig. 6.

E. M. F. in Closed Coil. The E. M. F. is generated in the dynamo-electric machine by movement of coils of wire through a magnetic field. We shall now consider the E. M. F. generated in a closed coil when moved in different ways through a magnetic field.

The dots in Fig. 6 represent a uniform magnetic field passing upward through the paper. *A B C D* represents a closed conducting coil, and let us suppose it is moved to the right, as indicated by the arrow. In such an event, sides *A* and *C* cut no lines of force, and no E. M. F. is generated by them. Side *B*, however, cuts the field, and by applying Fleming's rule it is evident that an E. M. F. is generated in the direction shown by the arrow applied to *B*. Also, as side *D* is subject to the same conditions, an E. M. F. is generated in the same direction as that in *B*, and as each cut the same number of lines of force in the same time, the E. M. F.'s generated are equal. Sides *A* and *C*, although not effective in cutting the field, serve as connecting conductors for the other sides. It is clear from the figure that the E. M. F.'s in *B* and *D* oppose each other, and therefore no current flows. In a similar manner it may be shown that no current will flow, no matter how the coil is moved, provided it always lies in a plane perpendicular to the magnetic lines. The E. M. F. generated in one part of the coil will always be opposed by an equal and opposite E. M. F. generated in the remaining part.

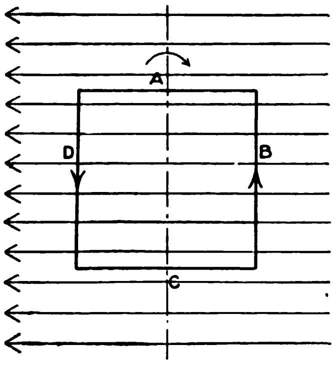

Fig. 7.

When, however, the coil is turned about an axis, the result is different. This may be understood by considering Fig. 7. Here the magnetic lines are represented as passing from right to left, and the coil as being turned about an axis in the direction indicated. The sides *A* and *C* cut no lines of force, and therefore generate no E. M. F. For the position shown, side *B* is moving downward through the paper and cuts directly across the lines and generates an E. M. F. in the direction indicated. Side *D* is moving upward, and therefore generates an E. M. F. in an opposite direction to that in *B*. These two E. M. F.'s, therefore, act in the same direction through the coil, and a current flows; the full E. M. F. of the coil being the sum of that generated by each side. This applies to every position of the coil as it rotates about its axis.

While the coil rotates, the number of magnetic lines passing through it is constantly changing, being a maximum when at right angles to the lines, and being zero when parallel to the lines, as in the position shown in Fig. 7. On the other hand, for the movements referred to when considering Fig. 6, the same number of lines passes through the coil at all times, and it may be stated as a general rule, that an E. M. F. is generated in a closed circuit when the same is moved so that the number of magnetic lines passing through it is altered during the motion.

APPLICATION OF PRINCIPLES TO DYNAMO-ELECTRIC MACHINES.

As an E. M. F. is induced in a conductor only while it moves through a magnetic field, thus cutting the lines, it is necessary for the production of a continuous current to have conductors arranged and interconnected so that some are always effectively cutting the field. This result is attained in the generator by rotating such conductors between the north and south poles of a magnet. We shall first consider a single conductor so rotated.

E. M. F. Induced by Rotating Single Conductor. In Fig. 8 suppose a conductor perpendicular to the paper to revolve with a uniform motion on the dotted circle between the *N S* poles, the field having a uniform density. The right-hand portion of the figure will then represent graphically the varying values of the induced E. M. F., and is called the curve of induced E. M. F.

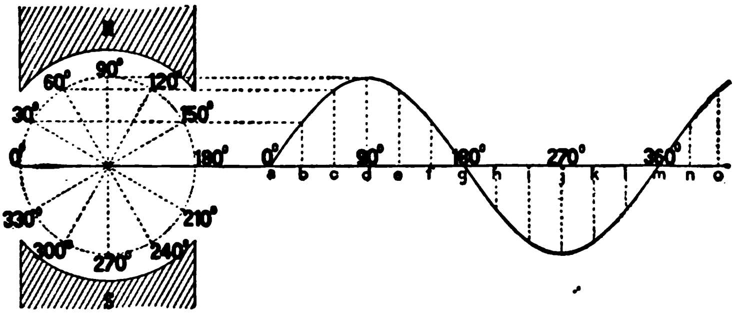

Fig. 8.

The horizontal line is divided into equal parts at points *a*, *b*, *c*, etc., and represent intervals of 30° in the rotation of the conductor. That is, the distance to the curve above or below the line at any point *a*, *b*, *c*, etc., represents the value of induced E. M. F. for the corresponding position of the conductor. For example, when the conductor is at the position 0°, it is then moving *parallel* with the lines of force, and no E. M. F. will be induced. Hence for 0° at *a* the value is represented as zero, which forms the starting-point for the curve. When the conductor has travelled 90° and is opposite the middle of pole *N*, it is cutting directly across the field, and at this time generates the maximum E. M. F. The curve is therefore at its highest point above *d*. At the intermediate points 30° and 60° between 0° and 90° the E. M. F. gradually increases as represented at *b* and *c*. As the conductor continues to revolve, a less and less number of lines are cut, until at 180° it is again moving parallel with the lines, and no E. M. F. is induced. This condition is represented at *g* where the curve crosses the line. At intermediate points between 90° and 180° the E. M. F. has a gradually decreasing value. After passing the 180° position the conductor again begins to cut a gradually increasing number of lines, but now cuts across them in the opposite direction to that during the first half of the revolution. The E. M. F. induced will therefore be in the opposite direction. Hence at 210° and 240° the E. M. F. gradually increases in an opposite direction, as shown at *h* and *i*. At 270° the maximum E. M. F. is being generated in the reversed direction, as represented at *j*. Upon completion of the 360° of one revolution, the E. M. F. again becomes zero. By continuing the rotation of the conductor the above series of changes will be repeated during each revolution. Hence during each revolution the induced E. M. F. rises from zero to a maximum, decreases, reverses, rises to a maximum in the opposite direction, and decreases to zero again.

Simple Form of Alternating Current Generator. We have seen that when a coil is rotated in a magnetic field, the opposite sides aid each other and the E. M. F. is double that produced by a single conductor. By the use of such an arrangement of a coil a simple form of alternating current machine is created. Fig. 9 represents the arrangement. The coil is mounted so as to rotate between the north and south poles of a magnet. The ends of the coil are connected to copper *collecting rings R R*, mounted on the shaft with the coil but insulated from each other. Upon each ring presses a stationary *brush B*, which is always in contact therewith, and serves to conduct the current to an outside circuit *W*. A complete circuit is then made up from one brush through the external wire *W* to the other brush, then to its collecting ring, through the coil to the other collecting ring, and to the first brush again. The alternating current produced by the rotation of the coil will then pass to the external circuit through the collecting rings and brushes, and during one-half of a revolution the current will pass in one direction and during the remaining half in the opposite direction. The current in the external circuit is available for doing work, and may be passed through motors, lamps, heating appliances, etc.

The Commutator. For the purpose of producing a direct current from the alternating current induced by a rotating coil, a device called a *commutator* is necessary. Its simplest form is shown in Fig. 10, and consists of a split copper ring, the two *segments* of which are insulated from each other, and each segment is secured to one end of the rotating coil. Although an alternating E. M. F. is induced in the coil, by the use of the commutator the current in the external circuit is always in the same direction. This may be understood from Fig. 10.

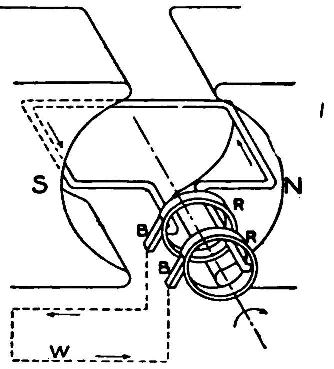

Fig. 9.

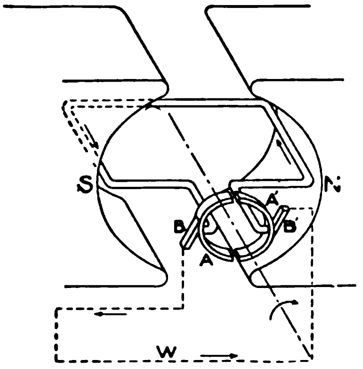

Fig. 10.

For the position of the coil shown, its current will be in the direction indicated and will pass to segment A, brush B, through the external circuit to brush B' and segment A' to the coil. As the coil continues to rotate, the E. M. F. gradually decreases, until when 90° from the position shown, the E. M. F. is zero. At this time the segments are located so that the brushes are about to break contact with one segment and make contact with the other. Further rotation induces an E. M. F. in the opposite direction, but the segments have then passed from one brush to the other, and the direction of current in the external circuit therefore remains unchanged. That is, when the current in the coil is in the direction indicated, segment A will *deliver* current to brush B, but when in the opposite direction segment *A* will be under brush *B'* and *receive* current from it. The commutator therefore serves to change the direction of the alternating current in the coil to a direct current in the external circuit.

Form of Curve. The curve of induced E. M. F. in the external circuit when a two-part commutator is used is shown in Fig. 11, and is the same as that in Fig. 8, except that the negative portion of the curve is turned above the horizontal. The direction of the current is always the same, but rises to a maximum and falls to zero twice during each revolution, giving what is called a *pulsating* current. It must be remembered, however, that the form of curve shown is the theoretical curve, with the assumption that the speed is constant and the field density uniform. With the actual machine, of course, the conditions are modified more or less, and other considerations, such as self-induction and distortion of the field, materially alter the form of the curve.

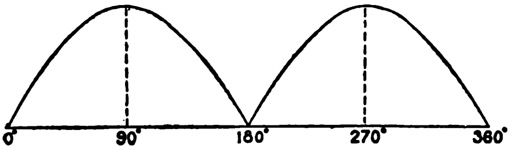

Fig. 11.

The coil, instead of consisting of a single turn, may be made up of two or more, as shown in Fig. 12. The sum of the electromotive forces induced in each turn is the resultant E. M. F. of the coil. Hence if there are n turns, the resultant E. M. F. will be n times the E. M. F. induced in one turn.

Owing to the fact that a pulsating current is generally undesirable for practical work a two-part commutator is now seldom used. The current is rendered nearly constant in value, however, by the use of several coils and a commutator made up of a corresponding number of segments. The coils are interconnected so that the E. M. F. induced in each is added to that of the others. The various methods of connecting will be considered on following pages, and only the principle will now be considered.

Suppose we have two coils at right angles to each other revolving in a magnetic field, and connected in such manner as to assist each other and yield a direct current to the external circuit. Then, while the maximum E. M. F. is induced in one coil, no

E. M. F. will be induced in the other, and at intermediate points there will be gradual changes. In Fig. 13 the dotted lines indicate the E. M. F.'s induced separately in the two coils, one being 90° in advance of the other. The combining of the two curves produces the curve in full lines, which is formed by taking the sum of the dotted curves. The upper curve therefore represents the fluctuation in E. M. F. of the combined coils, and it is evident that the amount of fluctuation is greatly reduced. In a similar manner it may be shown that a further increase in the number of coils, spaced uniformly, will cause less and less fluctuation, and by using 30 or more coils, a practically constant current may be obtained.

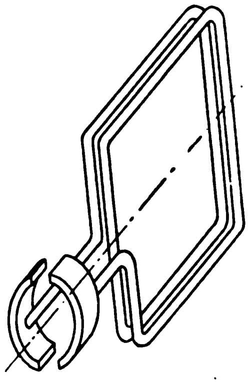

Fig. 12.

Parts of the Generator. Fig. 14 illustrates the essential elements of a generator, which consist of two principal parts,— the stationary *field magnets* and the *armature* which revolves between the poles. A current is passed through the winding around the *cores F F*, to produce the magnetic field in which the coils may rotate. A path for the magnetic lines is provided by the iron cores *F F*, the *yoke Y*, the pole pieces *N S* and the armature as indicated by dotted lines. The armature is made up of the coils and a soft iron core which serves to conduct the magnetic lines. All the coils are interconnected by means of the *commutator C*. The brushes *B B* press lightly upon the commutator and conduct the current to the external circuit, as has been pre-

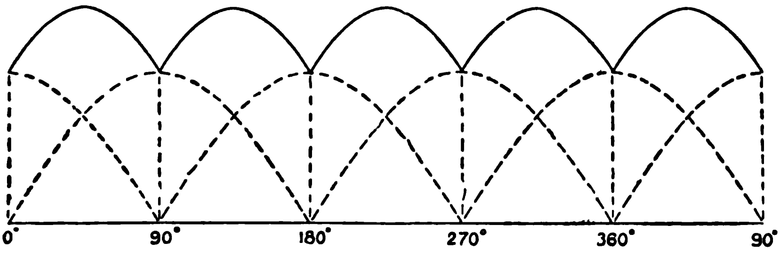

Fig. 13.

viously explained. The brushes are made adjustable and are carried by *brush-holders* on a *rocker* or *ring* provided for the purpose.

Frequently, and in all large machines, more than two poles are used. Fig. 15 illustrates the magnetic circuit of a dynamo with four poles. Machines having two poles are called bipolar machines, while those with more than two poles are called multipolar. Some machines have as many as 32 poles. The magnetic circuit is always of such form and construction as to produce a strong field in which the armature rotates. For this purpose it is desirable to have the length of the magnetic circuit, or the distance through which the lines of force pass, as short as possible. The material of this circuit is soft iron or soft steel, in order that the field may have great density.

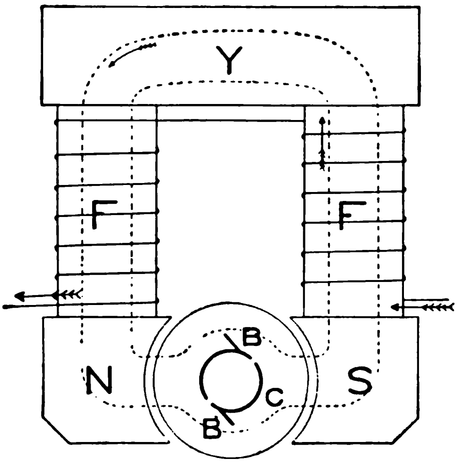

Fig. 14.

Referring to Fig. 14, it will be seen that the magnetic lines pass through the yoke, field cores and pole pieces, then pass across air spaces, called the *air gaps*, and then through the armature core. The armature core is sometimes in the form of a drum and sometimes in the form of a ring, and is always made of very soft sheet iron or soft steel. Since the magnetic lines pass through air with great difficulty compared with the case of passing through iron, the air gaps are always made as small as mechanical considerations will permit.

The armature is composed of the core above mentioned and the copper coils or windings about the core. The core serves to conduct the magnetic lines from one pole piece to the other; it is mounted upon a supporting frame of cast iron which is firmly secured to the driving shaft and therefore rotates with it. The shaft is usually supported in self-oiling and self-aligning bearings, and must be constructed so that the armature will always be centered between the pole pieces.

Energy Required to Drive the Dynamo. Although there is no mechanical resistance to the rotation of the armature except friction, the mechanical energy required to drive the armature varies with the amount of electrical energy obtained. When no current is delivered, the armature may be easily rotated; but as soon as a current flows, it reacts upon the magnetic field and opposes the rotation, and the greater the current, the greater the energy necessary to drive the machine. The amount of energy necessary to rotate the armature therefore increases as the load put upon the machine increases.

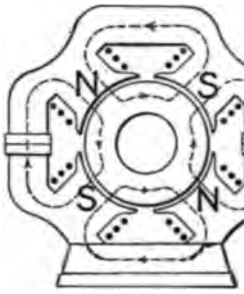

Fig. 15.

ARMATURE WINDINGS.

There are two distinct types of armature windings; one is called the *closed coil* and the other the *open coil* winding.

In the closed coil winding, all the conductors are interconnected so as to form an endless winding, consisting of two or more branches connected in parallel. In the open coil winding the conductors are joined in groups, each group containing in series all conductors which have a similar position with reference to the field. The current is supplied to the external circuit only from those groups which are generating the highest E. M. F.; all other groups being cut out of the circuit temporarily.

Armature windings may also be divided into *ring* and *drum* windings. In the first, the conductors are wound upon and in the form of a ring; in the second they are wound longitudinally upon a cylinder or drum. Open coil windings are used only in special types of machines, such as those for arc lighting; closed coil windings are used in machines for such common purposes as incandescent lamps, power and heating.

Closed Coil Ring Windings. The ring winding is the simplest, and therefore will be first considered.

Figs. 16 and 17 represent a four-coil Gramme or ring winding having a four-part commutator, and consisting of four coils wound about the iron core, with the junction of the coils connected to the commutator bars. The magnetic lines from the north pole pass to the iron core and then to the south pole, as indicated by the dotted lines, there being no magnetic lines across the space enclosed by the ring. Hence as the armature rotates, the conductors on the exterior surface of the ring cut across the magnetic lines twice during each revolution, while the conductors within the ring merely serve to connect the outside conductors in series, and are not effective in generating E. M. F. Each coil in Figs. 16 and 17 is made up of three external conductors, and therefore the E. M. F. of each coil will be three times that of a single conductor.

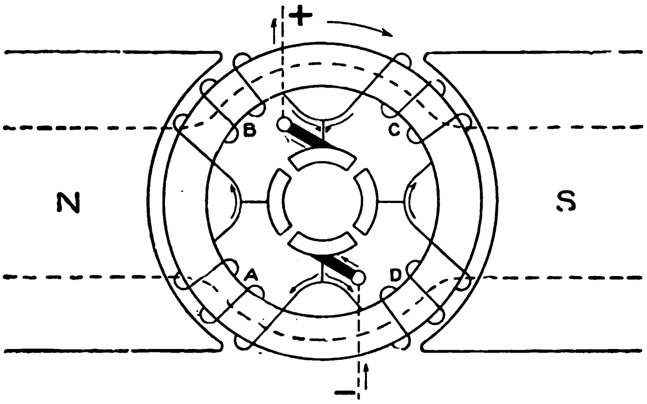

Fig. 16.

In Fig. 16 coils *A* and *C* are shown as having partly entered the magnetic field, and coils *B* and *D* about to pass out of the field. The path of the current is indicated by the arrows and passes from the external circuit to the lower brush and one bar of the commutator; it then divides and passes through coils *A* and *B* in series on the left, and coils *D* and *C* in series on the right; it then unites, passing to the upper commutator bar and upper brush to the external circuit. As there are two coils in series, the total E. M. F. will be the sum of the E. M. F.'s of the two coils for this position.

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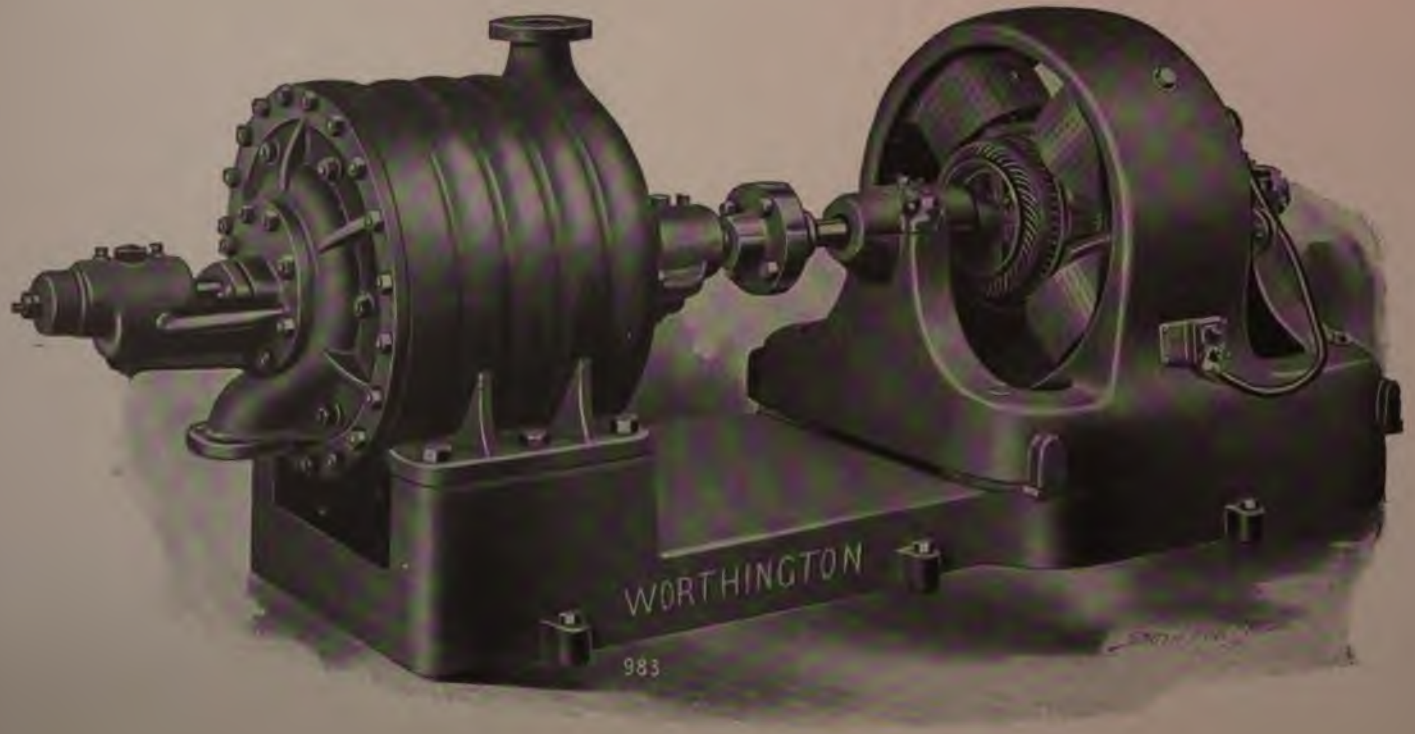
ASTOR, LENOX
TILDEN FOUNDATIONS



FIVE-STAGE MOTOR-DRIVEN TURBINE PUMP.

Adapted to Heads up to 750 Feet.

Fig. 17 shows the position after the armature has advanced 45° from that shown in Fig. 16. Coils *A* and *C* are then generating the maximum E. M. F., and the current passes from the lower brush through coils *A* and *C* in parallel to the upper brush. Coils *B* and *D* are in what is called the "neutral position," and generate no E. M. F.; in fact, they are temporarily *cut out* of the circuit, the commutator bars and brushes forming direct connections between coils *A* and *C*. Coils *B* and *D* are said to be *short-circuited;* that is, there is a direct connection of low resistance between the ends of these coils by the commutator bars and brushes, and no current will then pass through the coils.

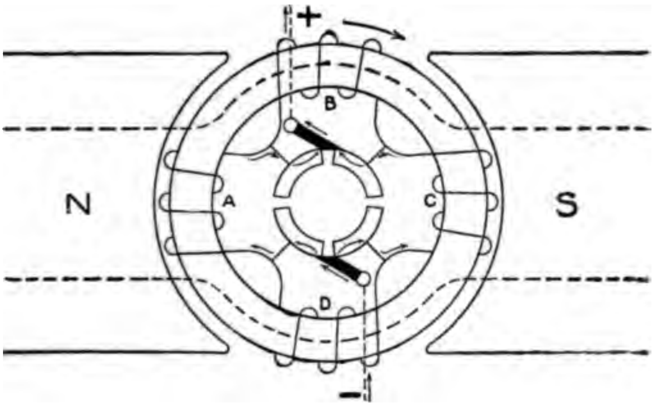


Fig. 17.

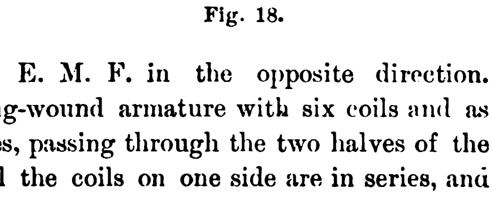


Fig. 18.

Upon further rotation, coils *B* and *D* will pass to the other side of the brushes and they will then generate an E. M. F. in the opposite direction.

Fig. 18 shows a ring-wound armature with six coils and as shown, the current divides, passing through the two halves of the winding in parallel. All the coils on one side are in series, and each add their portion to the total E. M. F.; the greater the number of coils, the less will be the fluctuation in the current, as explained on page 15. The E. M. F. of each coil varies at different positions, and the E. M. F. generated by some of the coils is increasing, while that of others is decreasing. The total E. M. F., however, remains practically constant when thirty or more coils are used.

Fig. 19 shows a ring winding for a machine with four poles. The winding is the same in form as for a bipolar machine, but the number of brushes and number of circuits through the armature is doubled. Therefore there are two positive brushes and two negative brushes. The two positive brushes are electrically united and connect with the positive wire of the external circuit, while the two negative brushes are united and connect with the negative wire of the external circuit. The current divides at each of the negative brushes, passing in parallel through four circuits (two for each brush) to the positive brushes.

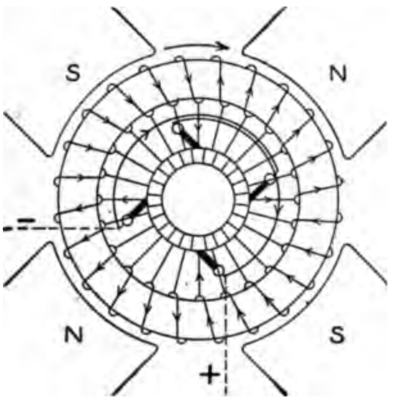


Fig. 19.

For machines with a larger number of poles, there would be a corresponding increase in the number of circuits through the armature.

The number of pairs of brushes may also be correspondingly increased or there may be but one pair since all terminal sections of the same sign (+ or —) can be soldered together.

Closed Coil Drum Windings. Drum windings are distinguished from ring windings in that all wires of the drum armature are distributed over the outside surface of the core. The winding forms a cage which envelops a cylindrical iron core. In the ring armature a large portion of the winding merely serves as connecting leads for that part which lies on the exterior of the core. In the drum armature, however, the only conductors serving as connectors are at the ends of the cylinder, and therefore a very different form of winding is necessary.

In the ring winding, adjacent conductors are connected directly in series with each other by looping around the ring core, but in the drum winding the return portion of the loop must lie on the exterior of the core, and in order that the E. M. F. induced in each part shall aid the other, the return portion must lie under a pole of opposite polarity to that under which the forward portion lies, as in Figs. 9 and 10.

The current in passing through the armature from brush to brush must gradually progress through each turn in series. Fig. 20 illustrates a portion of a drum winding, only two complete turns being shown. The small circles represent end views of conductors on the surface of the armature. The crosses and dots indicate the direction of current, the cross representing the tail of a retreating arrow and the dot the head of an approaching arrow. The current gradually progresses from bar to bar of the commutator as indicated by the arrows. The current passes to bar *A* from a conductor at the left of the core, under the influence of the south pole, then by a spiral connector to a conductor under the north pole, thence by a spiral connector at the back end of the core to a conductor under the south pole to bar *B*, then by a spiral connector to a conductor under the north pole, etc. It will be noticed that only the alternate conductors are connected in series, but the intermediate conductors are connected in series with each other to the right-hand half of the commutator.

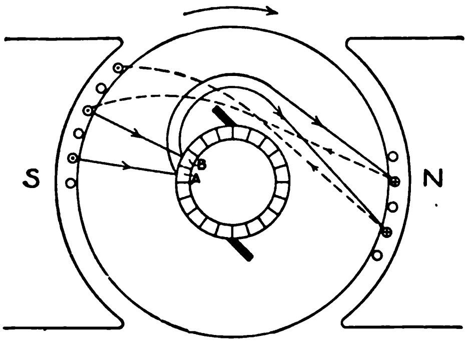


Fig. 20.

In order to make all end connectors of the same length and form, the commutator is usually turned 90° in advance of the position shown in Fig. 20, giving an appearance as in Fig. 21. This causes brushes of drum-wound machines to be opposite the poles instead of between them as in ring-wound machines.

Fig. 22 gives an end view of a complete drum winding in which there are ten complete turns and ten commutator bars. The windings form two circuits in parallel from brush to brush, as may be seen by tracing out the paths of the current. All parts of the winding are similar to each other, and a portion, called an *element*, is made in heavy lines to show clearly the general shape of the turns.

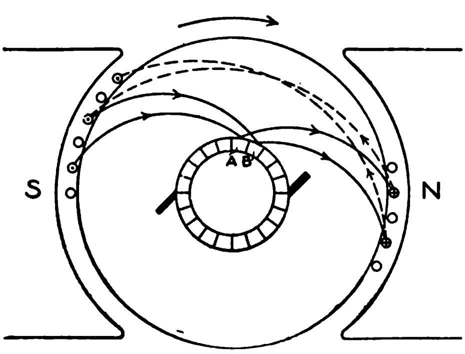


Fig. 21.

Fig. 23 shows a form of drum winding for a four-pole machine with fifteen turns and fifteen commutator bars. It will be seen from the figure that there are four separate circuits between the brushes, two being in parallel from each brush to the other.

Open Coil Windings. Open coil windings are similar to closed coil, except that there are no end connectors between the commutator bars; each coil being alternately cut in and then out of the circuit. Such a winding of four coils with four commutator bars is shown in Fig. 24. The opposite coils are connected in series and each pair of coils alternately make connection with the brushes.

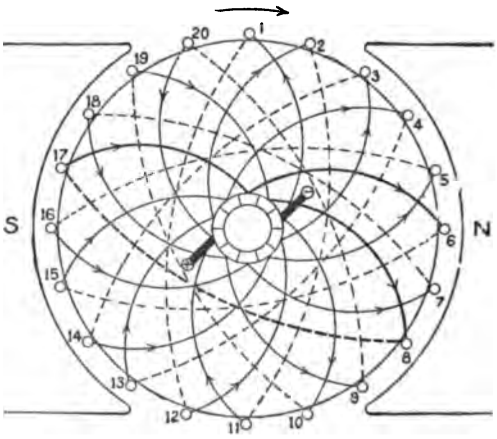


Fig. 22.

In General. Only the simplest forms of winding of the different classes have been considered on the preceding pages, and these were illustrated with figures showing a small number of turns. In the actual machine, however, the number of turns is much larger, and there are also a great variety of windings under each type, many of which are equivalent electrically but allow considerable variation in the mechanical construction. The number of poles and the number of brushes used also permit the connecting of the conductors in a variety of ways.

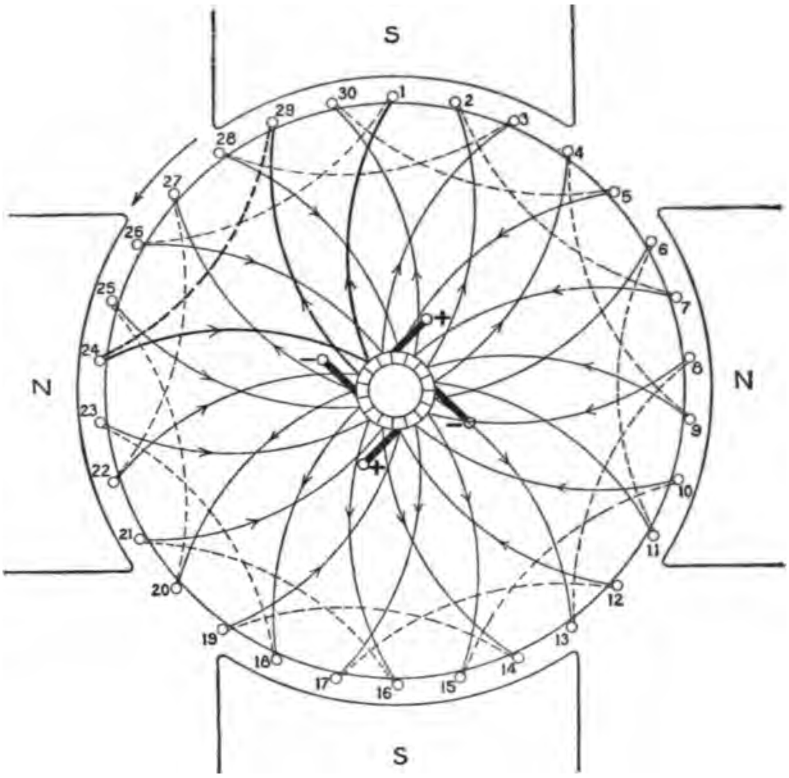


Fig. 23.

Calculation of E. M. F. Referring to page 7, it is seen that the value of E. M. F. in volts generated by a conductor moving in a uniform field is given by the formula,

$$E = \frac{L \times v \times B}{10^8} = L \times v \times B \times 10^{-8}$$

in which L is the length of the conductor in centimeters, v the velocity in centimeters per second and B the field strength in lines of force per square centimeter.

From the above formula we can arrive at the voltage of the actual machine. By reference to the figures showing armature windings, it appears that a single armature conductor is opposite a pole, and therefore *active* in cutting lines of force only during certain periods of each revolution. The field opposite a pole is practically of uniform strength, and when a conductor is not under a pole it is not effective in generating any E. M. F. Furthermore, there are usually two or more circuits through the armature connected in parallel, and the voltage of the machine will, of course, be the voltage of each circuit. For bipolar machines there are two circuits connected in parallel, and for multipolar machines there are usually as many circuits in parallel as there are number of poles, although the windings may be varied and interconnected in multipolar machines so that the number of circuits in parallel may be different from the number of poles.

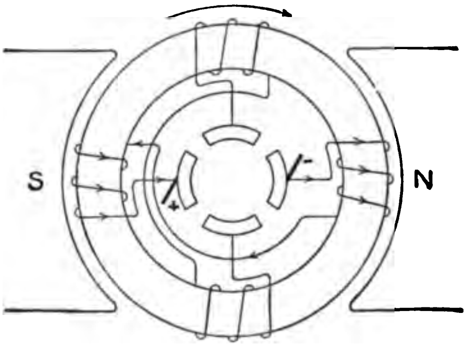


Fig. 24.

The voltage of any machine will therefore depend upon the number of conductors in series from brush to brush. For a bipolar machine, this will be one-half the total number of conductors on the surface of the armature. Of this one-half only those conductors opposite the pole piece are active. The voltage of such a dynamo will therefore be equal to the E. M. F. generated by a single conductor multiplied by one-half the total number of conductors, multiplied by that percentage opposite the pole pieces. This percentage is usually from 70 to 80. This may be expressed by a formula as follows,

$$E = \frac{L \times v \times B \times \frac{N}{2} \times p}{10^8} = \frac{L \times v \times B \times N \times p}{2 \times 10^8}$$

in which L, v and B equal the quantities previously given, N the number of conductors on the surface of the armature and p equals the percentage of conductors opposite the pole pieces.

Example. A bipolar machine has 800 surface conductors, each 12 centimeters long, and the percentage opposite the pole pieces is 80. The speed is 1,200 revolutions per minute and the diameter of armature is 40 centimeters. The field density opposite the pole pieces is 3,000 lines per square centimeter. What is the voltage of the machine?

Solution. For this case $L = 12$, $v = 3.1416 \times 40 \times \frac{1200}{60} = 3.1416 \times 40 \times 20 = 2513.28$, $B = 3{,}000$, $N = 800$, and $p = .80$.

Hence,

$$E = \frac{12 \times 2513.28 \times 3000 \times 800 \times .80}{2 \times 10^8} = 289.529 \text{ approx.}$$

Ans. 289.529 volts.

Example. What field density is necessary for a bipolar machine, in order to give a voltage of 220 at 900 revolutions per minute? The armature has 400 surface conductors, is 30 centimeters in diameter and 16 centimeters long, the percentage opposite the pole pieces being 74.

Solution. Here $E = 220$, $L = 16$, $v = 3.1416 \times 30 \times \frac{900}{60} = 1413.72$, $N = 400$, $p = .74$, and B is to be found.

Hence,

$$220 = \frac{16 \times 1413.72 \times B \times 400 \times .74}{2 \times 10^8}$$

or $$16 \times 1413.72 \times 4 \times 74\, B = 2 \times 10^8 \times 220$$

$$B = \frac{2 \times 10^8 \times 220}{16 \times 1413.72 \times 4 \times 74}$$

$$= 6{,}571 \text{ approx.}$$

Ans. 6,571 lines per sq. cm.

The formula on page 25 may be altered slightly to give the voltage of any machine, depending upon its winding. For example, for a four-pole machine with four circuits in parallel through the armature, the voltage will be that generated by one fourth of the surface conductors, and the formula becomes,

$$E = \frac{L \times v \times B \times N \times p}{4 \times 10^8}$$

It must be remembered that N equals the total number of surface conductors on the armature. For a ring-wound armature N would be equal to the number of turns, and for a drum-wound armature N would equal twice the number of turns.

Factors Determining Voltage. From the preceding it is clear that the voltage of a dynamo depends mainly upon three factors: speed, field strength, and length and number of conductors on the armature. The voltage may be increased by increasing any one of them. The speed of a machine is limited by mechanical considerations, and low speeds are greatly favored for this reason, and also to enable the driving engine and the generator to be directly coupled. The voltage obtained by using a large number of armature conductors is limited by troublesome sparking at the brushes, and the cost is also greatly increased. A high field strength is obtained by having large and powerful field magnets. A strong field greatly increases the weight of the machine and also increases the cost of the iron and field winding, but is advantageous on account of good regulation and reduction of sparking.

It must be remembered, however, that the formulas given above are for the theoretical values only, and these are somewhat reduced by armature reactions which will be considered on the following pages.

THE FIELD.

Magneto-Dynamo. The field of early forms of dynamos consisted of permanent magnets, and such machines were called *magneto-dynamos*. These were objectionable on account of their great weight (a very large magnet being necessary to give even a feeble field) and also on account of the gradual decrease in strength due to vibrations and inability to control the same. Very small machines of this type are still in use for light work, such as ringing telephone bells, but larger machines have been replaced by those having electro-magnets.

Ampere-Turns. The necessary magnetization of the wrought iron, cast steel and cast iron, which is used for the field frames of dynamos is produced by passing a current through the windings upon the frame, and the strength of the field depends upon the number of turns in the coils and strength of current passing through them. In fact, the magnetizing force is proportional to the product of the number of turns in a coil and the strength of its current. This product of number of turns and the current in amperes is called the *ampere-turns.* As far as the amount of magnetization is concerned, it is immaterial how the number of turns and current strength are related to each other as long as the product is the same. That is, it makes no difference whether there are 25 turns with 2 amperes, or 10 turns with 5 amperes; the product is 50 ampere-turns.

Saturation of Magnets. There is a great difference between the relation of the ampere-turns or magnetizing force and the field strength produced thereby for different values in the magnetizing force. When the number of ampere-turns is small, the magnetization of the iron will increase rapidly for a small increase of magnetizing force, and as the ampere-turns become greater, the resulting field strength increases almost in direct proportion. The increase is not, however, in direct ratio. This rapid increase in field strength continues to a certain point and then the increase begins to be less and less for an equal increase in ampere-turns, until finally a great increase in ampere-turns produces practically no increase in field strength. The iron is then said to be *saturated*, or to be in a state of *magnetic saturation*. An increase in the magnetizing force when this point is reached is, of course, of no advantage, and results simply in a waste of energy.

Fig. 25 shows graphically the relation between the magnetizing force and the corresponding field strength for a sample of wrought iron. In this plot the abscissae or horizontal distances represent the magnetizing force H in ampere-turns, while the ordinates or vertical distances represent the field strength or induction B, in number of lines per square centimeter. The small circles on the curve represent the points obtained by experi-

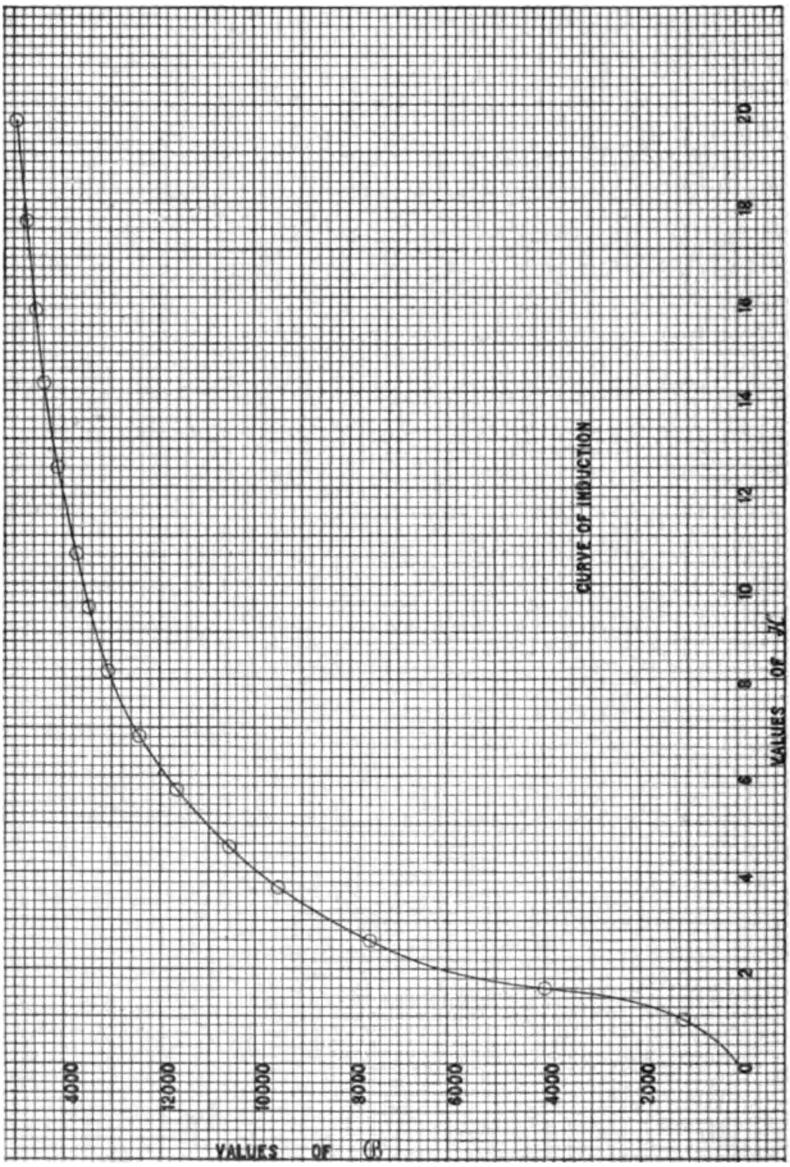

CURVE OF INDUCTION
VALUES OF $\mathcal{H}$
0
2
4
6
8
10
12
14
16
18
20
VALUES OF $\mathfrak{B}$
2000
4000
6000
8000
10000
12000
4000

Fig. 25.

ment, and by means of which the curve is obtained. It appears from the curve that an increase in magnetizing force from 0 to .5 does not increase the magnetic induction nearly as much as does the increase from .5 to 1.0, showing that it requires some little force to move the molecules from their irregular position into the more symmetrical arrangement which they are supposed to assume when magnetized. The value of the field strength is about 1,300 lines per square centimeter for 1 ampere-turn, and is 9,900 for 4 ampere-turns, showing the increase to be very rapid. For 8 ampere-turns the field density is 13,000 lines, showing the proportional increase to be much less for the field density than for the magnetizing force, and beyond this point the increase in field strength becomes gradually less and less, until the curve approaches a straight horizontal line, when the iron is saturated.

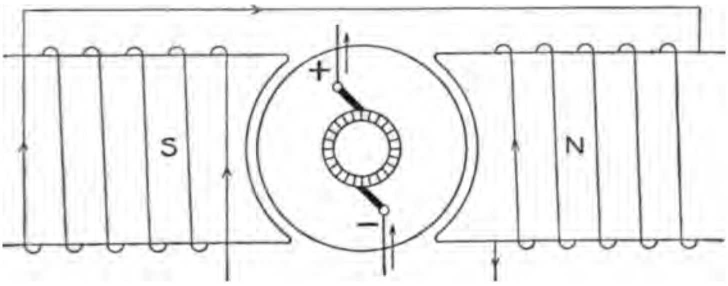


Fig. 26.

Types of Field Windings. There are four different types of field windings depending upon the method of excitation, giving rise to the following four classes of dynamos:

1. The *separately excited* dynamo.
2. The *series* dynamo.
3. The *shunt* dynamo.
4. The *compound* dynamo.

Each will now be briefly considered in the order named.

Separately Excited Dynamo. A separately excited dynamo is one having its field coils excited from some outside source, such as a battery or another dynamo. Fig. 26 represents such a machine, the two poles being excited by an outside current, and the current from the armature being available for supplying lamps, motors, etc. In the separately excited machine the field excitation may be maintained nearly constant irrespective of the change in load put upon the dynamo, but it requires an outside current supply. There are but few direct current machines having separate field excitation, but on account of the nature of the current derived from alternating current machines they are usually separately excited. A small direct current dynamo called its *exciter* is used for this purpose.

The Series Dynamo. We now come to consider dynamos which are self-exciting; that is, they supply their own field current and are therefore self-contained. Of these, the simplest is the series dynamo or *series-wound* machine, and in this type the main current from the armature is passed through the field coils and then to the external circuit. Such a connection is represented in Fig. 27. As these coils carry the main current of the machine they are of comparatively large size, but owing to the large current, only a small number of turns are required to give the necessary magnetization.

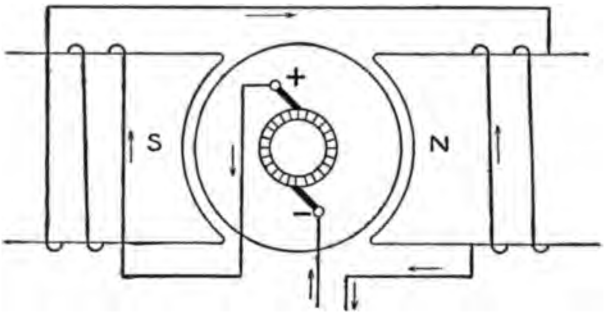


Fig. 27.

The series dynamo has the disadvantage that it cannot be made to start action until a certain speed has been obtained, unless the resistance of the external circuit is below a certain limit. Furthermore, the dynamo requires a special regulator to control the current and voltage with change of load, and about the only practical use for which it is adapted is for operating arc lights.

Shunt Dynamo. In the shunt dynamo or *shunt-wound* machine, the current from the armature has two paths through which to flow. One is through the external circuit and the other is through the field coils. The connections are represented in Fig. 28. The current from the armature divides at the positive brush and passes through the external circuit to the negative brush, and also through the shunt windings to the negative brush,

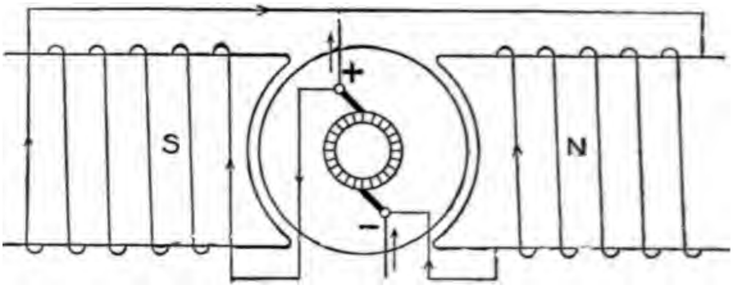


Fig. 28.

the field coils acting as a shunt to the external circuit. In this machine the field windings consist of many turns of fine wire, and take only a small part of the current from the armature; they

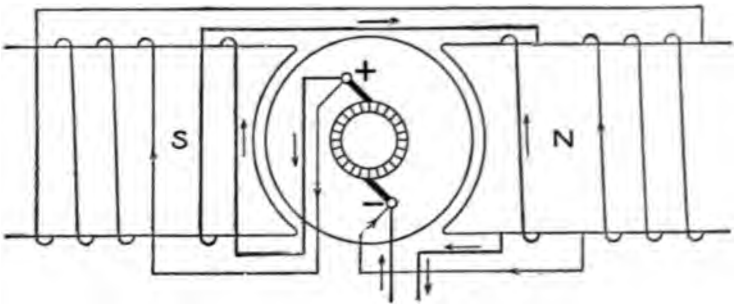


Fig. 29.

differ greatly from the series machine where there are but few turns carrying a large current.

The shunt-wound machine is much better adapted for practical service, such as lighting, and for supplying current to motors, than the series machine, but has been largely replaced by the machine next to be considered.

Compound Dynamo. The compound dynamo or *compound-wound* machine is a combination of the series and shunt windings.

The connections are shown in Fig. 29. In addition to the shunt winding connected from brush to brush, the main current is also passed through a few turns of large wire in series with the external circuit. With this arrangement the disadvantages of the shunt machine are overcome, and a machine which requires almost no attention during changes in load is produced; that is, the machine is practically self-regulating, and is used almost entirely for supplying current for incandescent lighting and power.

The action of the above considered machines is more fully considered in a following section.

Self-Excitation. As the energy required to excite the field magnets is a very small part of that which the machine is capable of supplying, it is evident that after a machine is once running there is no difficulty in maintaining the field strength. The question naturally arises as to the production of current at starting. This is explained by the fact that iron, after it is once magnetized, retains a certain amount of magnetism after the magnetizing force is withdrawn; this is called *residual* magnetism. Hence as the armature is rotated within this weak field, a slight E. M. F. will be generated which is sufficient to supply a feeble current to the field windings. This increases the field strength slightly, which in turn still further increases the E. M. F., and so on until the maximum voltage is attained. This action is called *building up*.

ARMATURE REACTIONS.

On the preceding pages we have considered the fundamental principles upon which the generator is based, and also its general construction. We shall now look into some of the important actions taking place during the operation.

We shall first consider the simple action of the armature unmodified by reactions, and then see how this condition is altered.

Simple Action. Fig. 30 represents an eight-coil ring armature of a bipolar machine. Coils *C* and *G* are moving directly across the strongest part of the magnetic field, and are therefore generating the maximum E. M. F. Coils *B* and *F* are just entering the field, and *D* and *H* are leaving the field and generating less E. M. F. than *C* and *G*.

Coils *A* and *E* are not cutting across the field, and therefore generating no E. M. F. Now all coils on the right-hand half of the ring are generating an E. M. F. in the same direction, and therefore assist each other to give the total E. M. F. of the machine, while all coils on the left-hand half are also assisting each other, but generating an E. M. F. in the opposite direction to that of the right-hand half. The current induced in the outside wires at the right-hand side approaches the observer, while the current in the outside wires at the left recedes from the observer, causing an ascending current in each half of the ring from the lower brush to the upper brush. It will be noted that each brush for the position shown, bears upon two commutator bars, and the upper brush takes the current directly from coils *B* and *H*, while the lower brush conducts the current directly to coils *D* and *F*. The thickness of brushes is always sufficient to bridge the insulation between commutator bars Coils *A* and *E* are therefore momentarily short circuited or cut out of the armature circuit, and as each coil takes these positions, each is successively short circuited. The current which the coil formerly carried then seeks the direct path through the commutator bar to the brush. After being short circuited and carrying no current, the coil is then grouped with the other half of the ring, and a current is set up in the opposite direction through the coil. Hence as each coil passes from one half of the ring to the other, the current through it in one direction is interrupted, which renders the coil temporarily inactive, and as it passes to the other side of the ring, a current is set up in the opposite direction. In this manner the commutation of currents takes place.

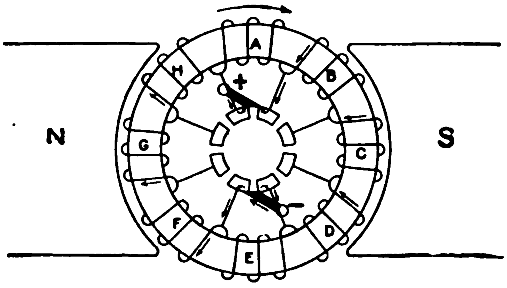


Fig. 30.

A plane through the inactive position of the coils is called the *neutral* plane, and coils *A* and *E* are said to be in the neutral positions.

Magnetic Field Due to Field Winding. The magnetic field, created by the field coils alone, and unaltered by armature reactions, is represented by Fig. 31. The small circles represent the cross section of each wire, of which only a few are shown, and the direction of current in the field coils is indicated by the dots and crosses within the circles. In those wires having crosses, the current is flowing from the observer, the cross indicating the tail of a retreating arrow, and in those wires having dots the current is flowing towards the observer, the dot indicating the point of an advancing arrow. The field, created by a current in the field coils only, is uniform and passes through the armature core as shown.

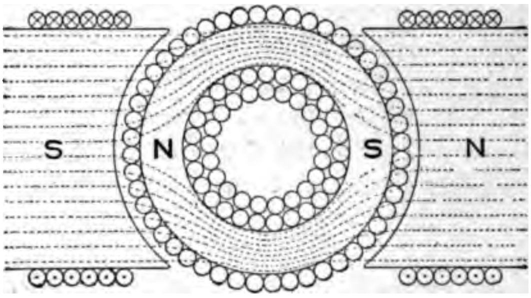


Fig. 31.

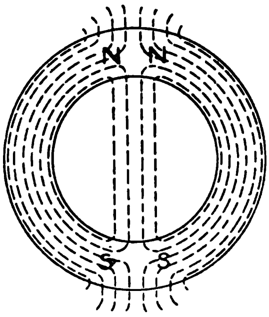
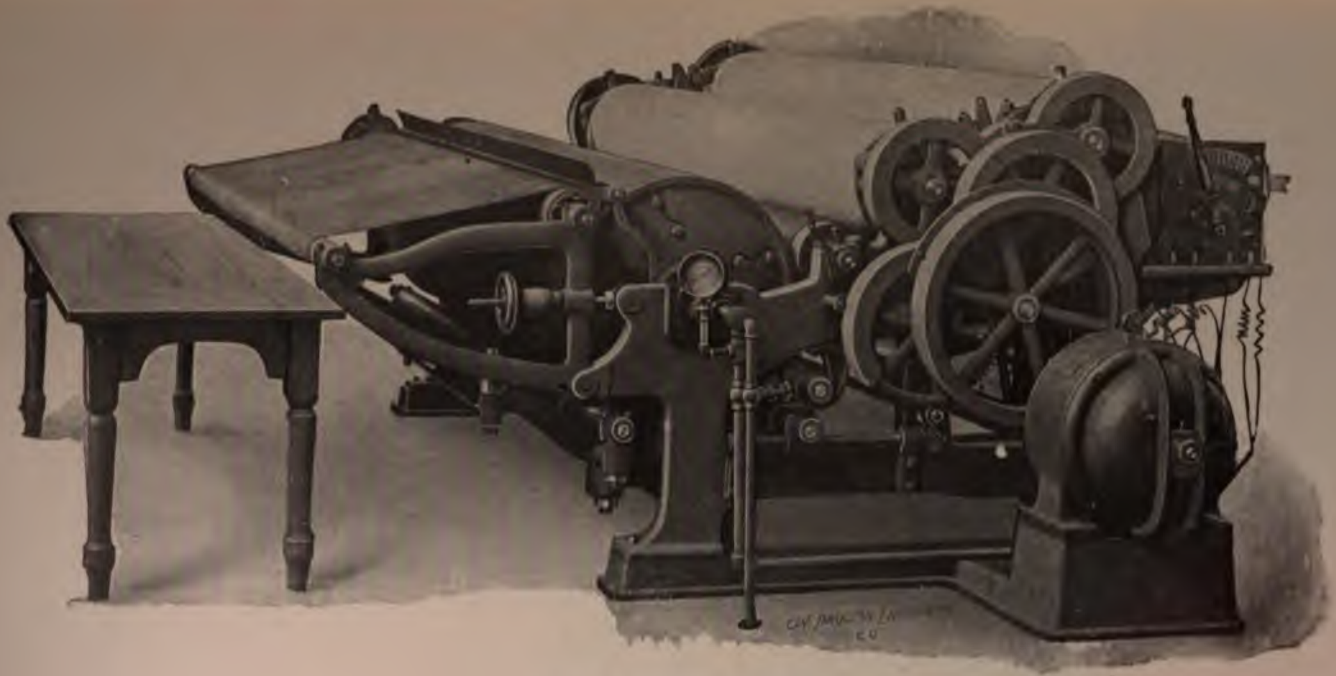


Fig. 32.

Magnetic Field Due to Armature Winding. When a generator is supplying current, the armature is magnetized by its own current, and the magnetic field in the armature due to its current alone is represented by Fig. 32. The current in each half of the ring magnetizes its half independently of the other, and for the arrangement shown in Fig. 30 each produces a north pole at the lower portion of the ring and a south pole at the top. The two like poles thus created adjacent to each other have a repellant effect and create what is termed a *consequent* pole, causing the magnetic lines to leave the ring at these points, part of the lines passing directly across the ring and part



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passing outside the ring in curved lines from the lower portion to the top.

When a ring thus magnetized is between the field poles, the poles will serve as a path for many of the lines, and a field such as represented by Fig. 33 results.

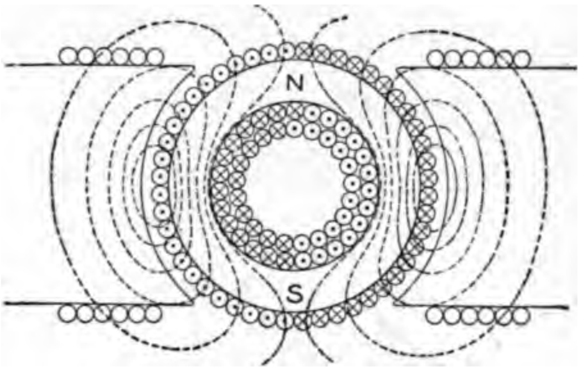


Fig. 33.

Resultant Field. When a machine is in operation, the magnetism due to both the field and armature windings is present, and the field obtained will therefore be the resultant of the two fields represented by Figs. 31 and 33. These fields, when united,

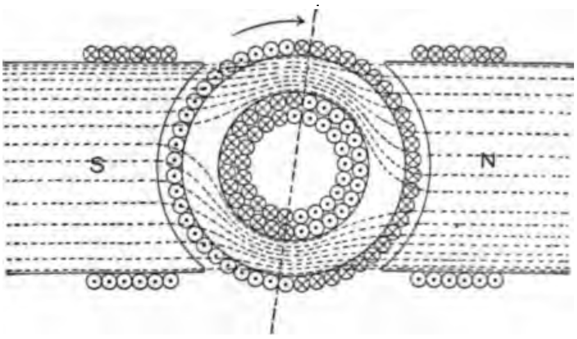


Fig. 34.

will give a resultant field, as represented by Fig. 34. The field due to the field windings being the stronger, will still maintain the same general course, but the effect of the armature is to produce a resultant field in an oblique direction. It also causes a crowding of the magnetic lines at the tips of the poles where the conductors pass from under the same, and a weakening of the lines at the tips which the conductors are approaching. It thus appears that the neutral plane is turned somewhat in the direction of rotation as indicated by the dotted line. After passing from under pole pieces, the conductors generate but little E. M. F., and when they are in the neutral plane they generate none whatever; therefore from the above it appears that the brushes should be set in such a position that coils will be short circuited when in the neutral plane. Hence the brushes, instead of being placed midway between the poles in a ring-round machine will be shifted slightly in the direction of rotation of the armature. The amount which the brushes are shifted from their mid-position is called the *lead* or *angle of lead.*

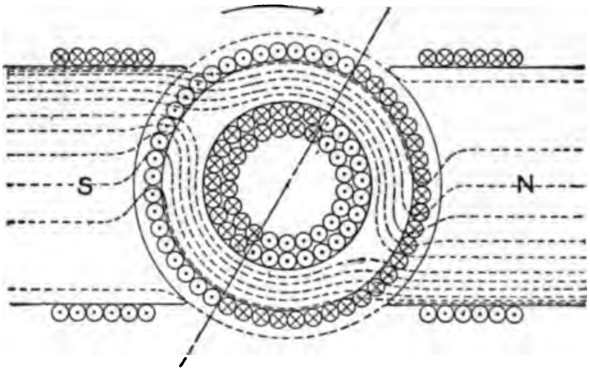


Fig. 35.

This shifting of the brushes causes a still further distortion of the resultant field, as the field due to the armature winding alone, instead of being vertical as represented in Figs. 32 and 33, will be inclined, and coincide with the neutral plane. This inclination aggravates the distortion, causing the neutral plane to be shifted to a greater degree than represented by Fig. 34. The actual result obtained will therefore be better represented by Fig. 35, all conductors on one side of the neutral plane carrying currents in an opposite direction to those on the other side.

There is another cause for additional shifting of the brushes which causes a slightly greater distortion. This is due to self-induction of the armature coils. From the preceding pages it appears that each coil is short-circuited as it passes by the brushes ; the current which the coil carried as it approached a brush ceases to flow, and as it passes to the other side, a current in the opposite direction is set up. On account of self-induction, however, the current which the coil formerly carried tends to continue, and the current in the opposite direction is choked back for a slight interval of time, as self-induction tends to oppose a decrease or increase of current strength. In order to counteract this effect, the brushes are shifted a slight amount in the direction of rotation, so that when each coil is short-circuited it is at that time already somewhat effective in cutting lines of force, so that a slight E. M. F. is generated which hastens the time of decrease in current in one direction, and assists the increase of current in the opposite direction.

We may sum up the effect of armature reaction as follows:

1. The magnetic field due to the armature windings is at right angles to that of the field windings, giving a resultant distorted field.

2. On account of this distortion, and in order to prevent sparking, the brushes must be shifted in the direction of rotation of the armature, and this new position of the brushes in itself produces a still greater distortion.

3. The further shifting of the brushes to overcome the effects of self-induction causes additional distortion.

Shifting of Brushes with Variable Load. When the armature supplies no current and therefore has no load, the field is substantially uniform, as no distortion due to the armature exists. The brushes may therefore be set at the mid-position between the poles. When the load is light, the small armature current causes but little distortion, and therefore the brushes need only a slight lead to secure sparkless running. As the load increases and the armature current becomes greater, the distortion is correspondingly increased, and consequently the proper position for the brushes changes with the load. Hence in the operation of generators, a variation in load will cause sparking at the brushes unless they are shifted to the proper positions. Many machines are now so well designed that but little shifting is necessary from no load to full load, and in some machines the necessity is entirely overcome by special compensating arrangements. Of course, if the field due to the field windings is made very powerful compared with that due to the armature, the distortion will be proportionately less, and in many machines now made, where this plan is carried out, there is little or no need of shifting the brushes with change in load.

Distortion Due to Drum-Wound Armatures. In the above discussion of armature reactions we have referred to distortion due to ring-wound machines only. The same effect in a lesser degree takes place with drum-wound armatures.

Magnetic Leakage. If the magnetic circuit is well designed and made of ample cross-section, practically all the lines of force will pass through the armature core from pole to pole. All lines which do not pass through the core are of course useless, and the E. M. F. generated is less in a corresponding degree. Fig. 36 illustrates the manner in which lines may pass from pole to pole without being of any service. This is called magnetic leakage.

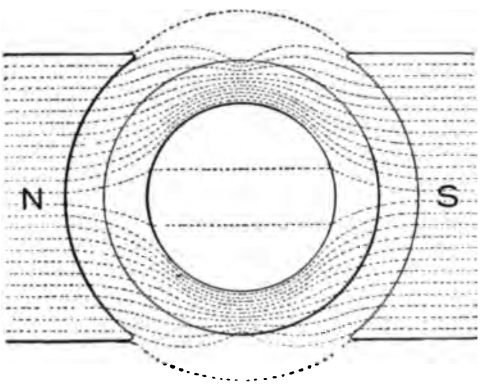


Fig. 36.

LOSSES IN THE GENERATOR.

There is always some loss in converting the mechanical energy necessary to drive a generator into electrical energy. That is, if 15 horse-power is necessary to drive a certain machine, the equivalent electrical energy derived from the same is always somewhat less. For example, the electrical equivalent of 15 horse-power is 15 × 746 = 11,190 watts, but instead of having this amount available at the dynamo terminals, there may be perhaps 90 per cent of this value, or 10,071 watts.

We shall now consider separately the various losses, all of which are dissipated in the form of heat.

These may be classified in two groups, known as the *electrical* losses and the *stray power* losses, and are as follows:

Electrical losses.

(*a*) Armature conductor $I^2 R$ loss.
(*b*) Field wire $I^2 R$ loss.

Stray power losses.

(*c*) Friction of bearings.
(*d*) Friction of brushes.
(*e*) Friction due to air resistance.
(*f*) Waste currents in coils during commutation.
(*g*) Hysteresis in armature core.
(*h*) Eddy or Foucault currents in armature core.
(*i*) Eddy or Foucault currents in pole pieces.
(*j*) Eddy or Foucault currents in armature conductors.

Of these the electrical losses vary with the load put upon the machine, whereas the stray power losses remain practically constant for all loads. As the stray power losses are always present to the same degree whatever the load may be, it is desirable that they should be as low as possible, since on light loads they may be a considerable proportion of the total power.

Electrical Losses. The electrical losses are those due merely to the resistance of conductors through which a current flows, and may be computed by taking the square of the current passing multiplied by the resistance, or $I^2 R$; where I is the current and R the resistance of the circuit. All circuits carrying a current, whether windings of a generator or mains which distribute power, are subject to this loss of energy. Hence if the resistance and current are known, the power lost may be readily obtained.

For example, if the resistance of a circuit is 80 ohms and the current 40 amperes, the power lost will be $40^2 \times 80 = 128{,}000$ watts, or 128 K. W. The power lost may also be computed if the current and E. M. F. applied to the circuit are known, by taking the product of the two quantities. This is evident, as from Ohm's law $I = \frac{E}{R}$, and substituting this quantity for one I in $I^2 R$, we have $I \times \frac{E}{R} \times R = IE$, where E is the E. M. F., applied to the circuit. In the above problem the E. M. F. applied to the circuit is, by Ohm's law, $E = RI = 80 \times 40 = 3{,}200$ volts, and the loss in watts is, therefore, $40 \times 3{,}200 = 128{,}000$ watts = 128 K. W., the same as above.

The data for computing the loss in the field windings of a machine can be easily obtained. It is merely necessary to measure the resistance of the windings and the current in the same, or to measure the current and the voltage applied to the terminals of the field windings. The resistance of shunt windings will always be high and the current small, while the resistance of series windings will always be low and the current large.

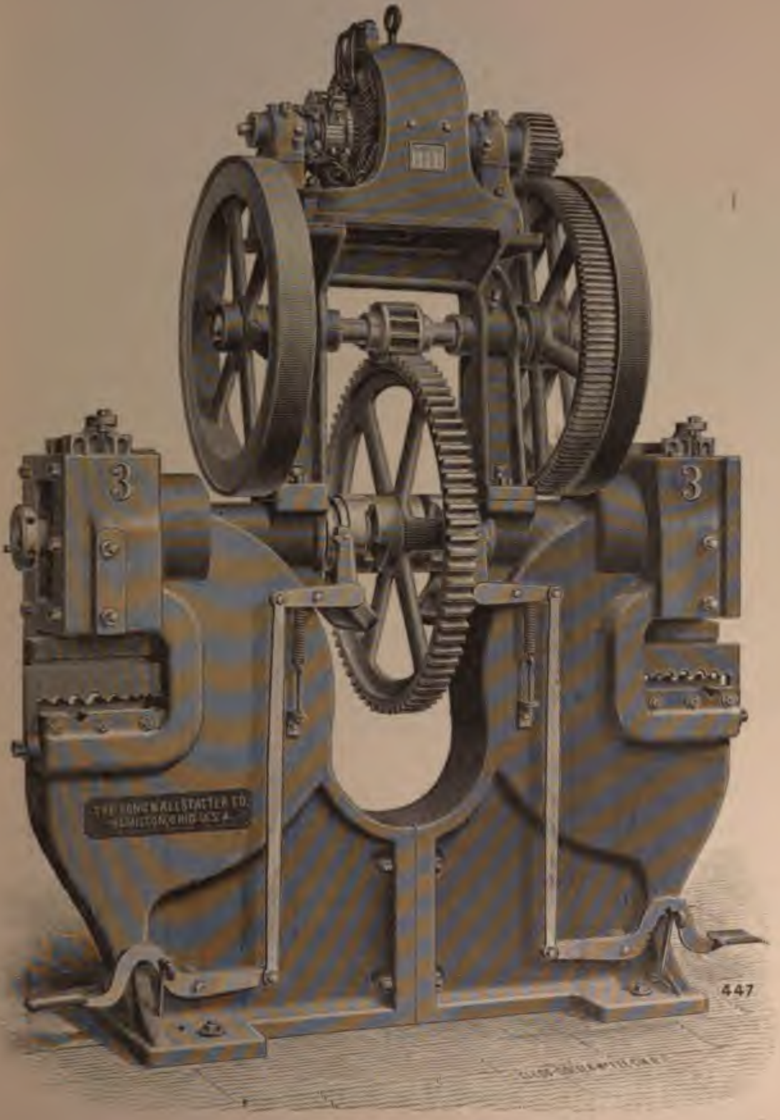
The data for calculating the loss in the armature is obtained with more difficulty. As the armature is itself generating an E. M. F., the fall of potential in the armature due to its resistance or the *drop* in the armature cannot be measured, and we are therefore compelled to compute the loss from resistance measurements and must use the formula $I^2 R$. The current can be easily measured, but there is some difficulty in measuring the resistance accurately. In this resistance, the armature winding, commutator, brushes and resistance of contacts between commutator and brushes are included. The total resistance is very small, and therefore a slight error in its measurement will make a considerable percentage difference. Also the resistance must be measured when the armature is not rotating, and the measurement obtained may be somewhat different from the resistance when the machine is in operation.

As the resistance of the conductors is greater when hot than when cold, the resistance measurements for calculating the loss in the armature as well as in the fields must be made after the machine has been in operation at full load for a few hours, when all parts will be thoroughly warmed up.

Example.— The resistance when hot of the shunt winding of a certain 120-volt 200-ampere shunt machine is 98 ohms. The resistance of the armature when hot is .019 ohm. What are the electrical losses at full load?

Solution.— The voltage of the machine which is applied to the shunt terminals is 120 volts, and by Ohm's law the current in the shunt windings is

$$I = \frac{E}{R} = \frac{120}{98} = 1.22 \text{ amperes.}$$



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The loss in the field winding is therefore $I^2 R = 1.22^2 \times 98 = 146$ watts approximately.

Both the main current and the shunt current pass through the armature; hence the armature current is 201.22 amperes, and the resistance is .019 ohm; the loss is therefore $(201.22)^2 \times .019 = 769+$ watts.

The electrical losses are consequently $146 + 769+ = 915$ watts.

Ans. 915 watts.

Example.— A 500-volt compound-wound generator is designed to supply 650 amperes. The armature resistance is .009 ohm. The current in the shunt winding is 3 amperes, and the resistance of the series winding is .0011 ohm. Find the total electrical loss of the machine.

Solution.— As the current in the shunt field winding is 3 amperes, and the voltage applied to the terminals is 500, the loss in watts is given directly by their product, or $3 \times 500 = 1{,}500$ watts.

As the main current of the machine passes through the series winding, the resistance of which is .0011 ohm, the loss therein is $650^2 \times .0011 = 464.75$ watts. Likewise the loss in the armature is $653^2 \times .009 = 3{,}837.6$ watts.

The total loss due to resistance therefore equals $1{,}500 + 464.75 + 3{,}837.6 = 5{,}802$ watts.

Ans. 5,802 watts.

Example.— A 220-volt compound dynamo delivers 300 amperes. The armature resistance is .014 ohm, the shunt winding takes 2.18 amperes, and the fall of potential in the series coil is .54 volt. What are the electrical losses?

Solution.— The loss in the shunt field is $220 \times 2.18 = 479.6$ watts. The current passing through the armature is $300 + 2.18 = 302.18$ amperes, and the armature loss is therefore

$$(302.18)^2 \times .014 = 1{,}278.4+ \text{ watts.}$$

The loss in the series coil is the product of the lost voltage (i.e., the drop) in it and the current; that is, $.54 \times 300 = 162$ watts. Hence the total electrical losses are $479.6 + 1{,}278.4 + 162 = 1{,}920$ watts.

Ans. 1,920 watts.

Friction Losses. The friction losses include those due to mechanical friction of the bearings and of the brushes upon the commutator and also the friction caused by the resistance of the air acting on the rotating armature.

The friction of the bearings varies with the type of machine, whether belt driven or direct connected to the engine, type of bearing, lubrication, etc.

The loss due to bearing friction was formerly considerable, but the bearings of modern dynamo-electric machines have been designed and constructed with great care with the result that friction from this source has been reduced to a minimum. The bearings are usually made self-oiling by means of metal rings which rest upon the shaft and dip into oil which is contained in a reservoir in the bearing. As the shaft revolves, the rings carry the oil up to the shaft. In this manner almost perfect lubrication is secured. In some cases ball bearings have been used with good results; they reduce friction and lessen the cost of lubrication. Ball bearings are not extensively used on account of some mechanical difficulties which have not yet been entirely overcome.

The brush friction is subject to great variation. It is important that the brushes bear upon the commutator with sufficient pressure to insure good electrical contact. Brush holders are usually arranged so that the pressure of the brushes may be varied to obtain the best results. Although brush friction may sometimes be considerable, it usually amounts to a very small percentage of the total loss.

The resistance of the air upon the armature is usually insignificant except when the armature is arranged to act as a fan for the purpose of ventilation, and even then the loss from this source is so slight that it need hardly be considered.

Hysteresis Loss. As an armature rotates, the magnetization of its core is constantly changing at every point. The magnetic lines in passing through the armature from pole to pole cause varying degrees of magnetization in its different parts, and the rotation of the armature brings every part of it successively through these changes. Hence that part of the armature in the neutral plane is magnetized to the highest degree with lines passing through it in one direction; when opposite a pole, the magnetization is a minimum, and when in the next neutral plane it is again magnetized to the highest degree but with lines passing in the opposite direction. All parts of the armature core are therefore being constantly magnetized in one direction, then demagnetized and magnetized in the opposite direction, again demagnetized, and so on as each pole is passed. This gives rise to what is called hysteresis loss, which will now be considered.

When a piece of iron is subjected to an increasing and decreasing magnetizing force, the magnetization for equal magnetizing forces will not be the same, and it is found that the magnetism lags behind the magnetizing force, or in other words, the metal has a tendency to maintain any magnetic state which it has once acquired. This property of iron is called *hysteresis*, from a Greek word meaning "to lag behind."

Fig. 37 shows the hysteresis curve of a piece of wrought iron, or the resultant magnetization when the magnetizing force is varied. The abscissæ represent the magnetizing force in ampere-turns per centimeter of length, and the ordinates indicate the resultant magnetization in lines per square centimeter. Abscissæ to the right of the zero point represent positive values and those to the left negative, while ordinates above the zero point are positive and those below are negative. The curve which begins at *A* shows that the iron had some residual magnetism before any magnetizing force was applied. As the magnetizing force is increased positively, the magnetic induction gradually increases as in Fig. 37, until point *B* of the curve is reached. Then the magnetizing force is gradually withdrawn, but the magnetic induction does not fall as fast as it previously rose, for when the magnetizing force is reduced to 10, the induction is nearly 14,000 lines instead of 12,800, as it was on the ascending curve. When the magnetizing force is reduced to zero, the induction is still high, as represented by point *C* of the curve. Increasing the magnetizing force still further in a negative direction gives an induction curve to point *E*.

A gradual decrease of the magnetizing force to zero and an increase in a positive direction to a maximum gives the curve through points *E F G H*. It may be noted that point *H* does not coincide with point *B*, although the magnetizing force is increased

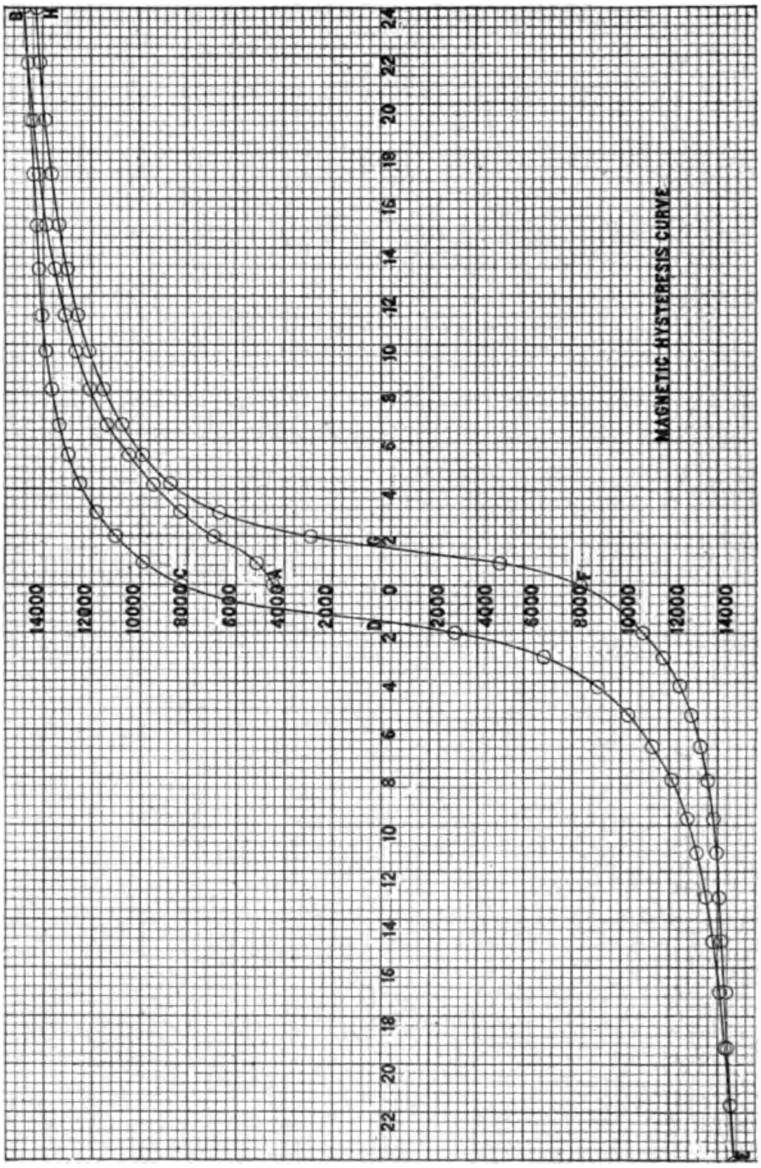
MAGNETIC HYSTERESIS CURVE
B
H
C
A
D
G
F
E
14000
12000
10000
8000
6000
4000
2000
0
2000
4000
6000
8000
10000
12000
14000
24
22
20
18
16
14
12
10
8
6
4
2
0
2
4
6
8
10
12
14
16
18
20
22

Fig. 37.

from zero to a maximum for both curves. However, in the first magnetization from *A* to *B* the induction had a considerable positive value at the beginning, whereas in the curve *F G H* it had a large negative value which had to be overcome. If the magnetizing force were now decreased, reversed, increased, etc., a second curve similar to *B C D E F G H* would be obtained. Such cycles of magnetism as described above always give curves with an enclosed area.

This series of changes is what takes place in the core of an armature, and it is evident that the resultant magnetism always lags behind the magnetizing force as if there were a certain molecular friction of the iron which had to be overcome.

There is, therefore, a certain loss of energy due to hysteresis which is dissipated in the form of heat. The amount of this energy is proportional to the area enclosed by the curve, and it is therefore an easy matter to judge of the comparative magnetic qualities of two samples of iron by plotting the hysteresis curve of each.

The harder the iron, the greater the hysteresis loss. This loss varies as the 1.6 power of the magnetic induction and is also proportional to the rate at which the reversals of magnetism take place, and of course, the greater the amount of metal in which the reversals occur, the greater the total hysteresis loss.

The heating which occurs in the core of an armature due to hysteresis should not be confused with the additional heating due to eddy or Foucault currents. Hysteresis causes heating even if the core is carefully laminated.

Fig. 38 shows two hysteresis curves drawn one over the other, one of which is from a sample of wrought iron and the other from a sample of steel.

The curve enclosing the smaller area is for wrought iron, and the larger for steel. Since the area enclosed by the hysteresis curve is the measure of energy dissipated in heat due to hysteresis, it is evident that the hysteresis loss for wrought iron is much less than for steel. Wrought iron would, therefore, be better adapted for use in armature cores.

The loss due to hysteresis cannot be accurately determined. For very soft iron where the hysteresis curve encloses a small

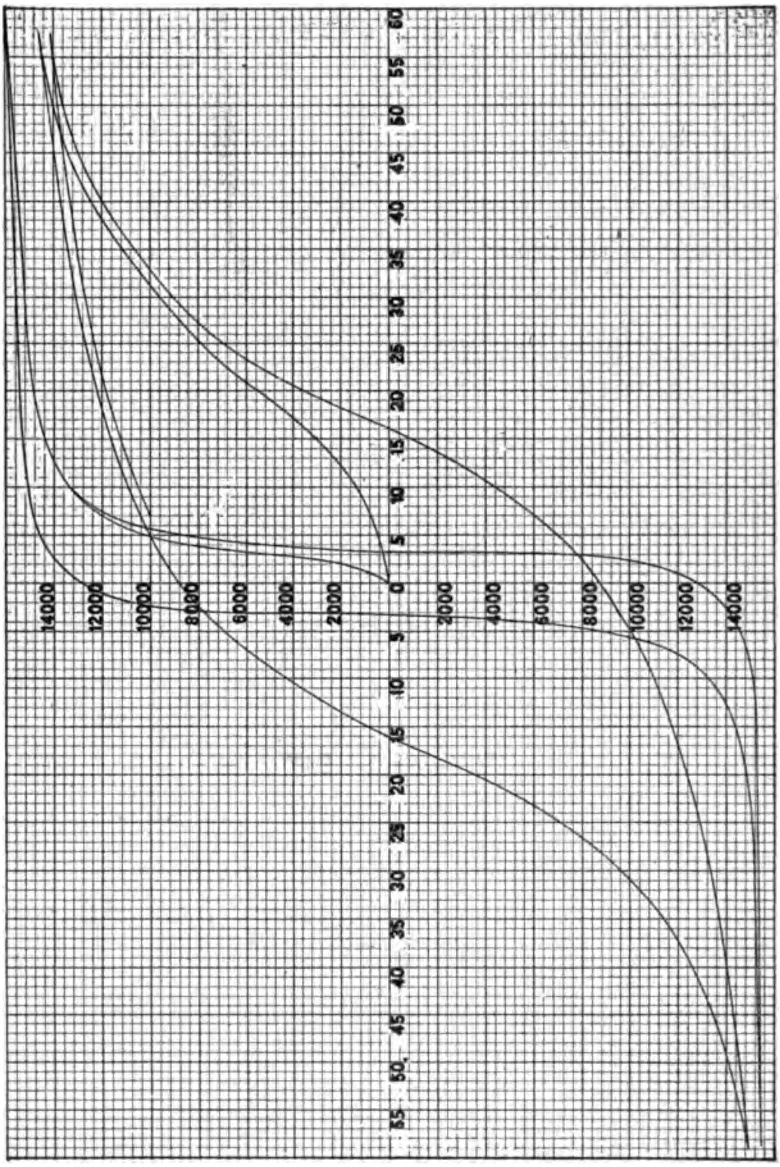
60
55
50
45
40
35
30
25
20
15
10
5
0
5
10
15
20
25
30
35
40
45
50
55
14000
12000
10000
8000
6000
4000
2000
2000
4000
6000
8000
10000
12000
14000

Fig. 38.

area the loss of energy during a complete reversal of magnetism is slight; with hard iron the amount of energy wasted per cycle is somewhat greater, but in practice the loss from this source is usually small. In order that this loss may be as small as possible the softest wrought iron or steel should be selected for armature cores.

Eddy Current Loss. We know that whenever conductors are moved in a magnetic field in such a manner as to cut across the lines, or when the field about the same is varied, an E. M. F. is induced which will cause a current to flow if a closed circuit exists. This principle applies to large metallic masses as well as to the conductors, and therefore currents may be set up in a generator where they are useless, thus causing undesirable heating of parts and loss of energy. Such currents are called eddy or Foucault currents.

The armature core, if made of one solid mass, is subject to these wasteful currents to an excessive degree, since it consists of a conducting mass revolving in a magnetic field. It is evident that the outer surface of the armature core cuts across the magnetic field the same as the conductors upon it, and an E. M. F. is therefore induced in the iron itself, tending to set up currents near its surface. The direction of these currents will be at right angles to the lines of force or the induced current in the exterior of the armature core will be parallel to the current in the armature conductors. The interior portion of the core serves to complete the circuit for these currents, and therefore innumerable currents, due to this cause, will exist in the core itself. The E. M. F. induced may be slight, but the resistance of the core is so small that the resultant currents may be large. These currents are always strongest near the exterior surface of the armature core. This eddy current loss described above varies as the square of the speed and also as the square of the magnetic induction.

Lamination. The value of such currents can be decreased by reducing their E. M. F. or by increasing the resistance which is offered to their flow. These results can be accomplished by constructing the armature core of thin sheets of iron carefully insulated from each other. These thin sheets or discs are placed perpendicular to the axis of the armature, thus being perpendicular to the direction of induced currents, but parallel with the lines of force passing through the core. Consequently they do not interfere with the passage of magnetism from pole to pole, nor increase the magnetic resistance of the armature. They do, however, effectually interrupt and reduce the eddy currents because such currents can then exist only within each separate disc, as shown in Fig. 39, and if the discs are made sufficiently thin and the insulation between them is good, the loss due to wasteful currents is slight. An armature built up of discs or thin sheets of iron is said to be laminated. The thickness of the discs should not exceed two millimeters, and they should be insulated by varnished paper, enamel, or by being slightly oxidized on the surface.

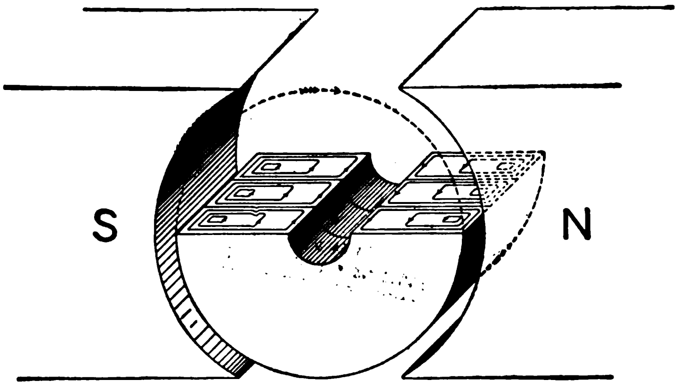

Fig. 39.

Eddy Currents in Pole Pieces and Armature Conductors. Polar tips in which magnetization varies become heated. Hence tips are now laminated, the laminations being parallel to the lines of force but perpendicular to the direction in which currents would be induced. Armature conductors are also subdivided for the same reason, and the loss in eddy currents is reduced to a total of usually less than one-half of 1%.

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ASTOR, LENOX
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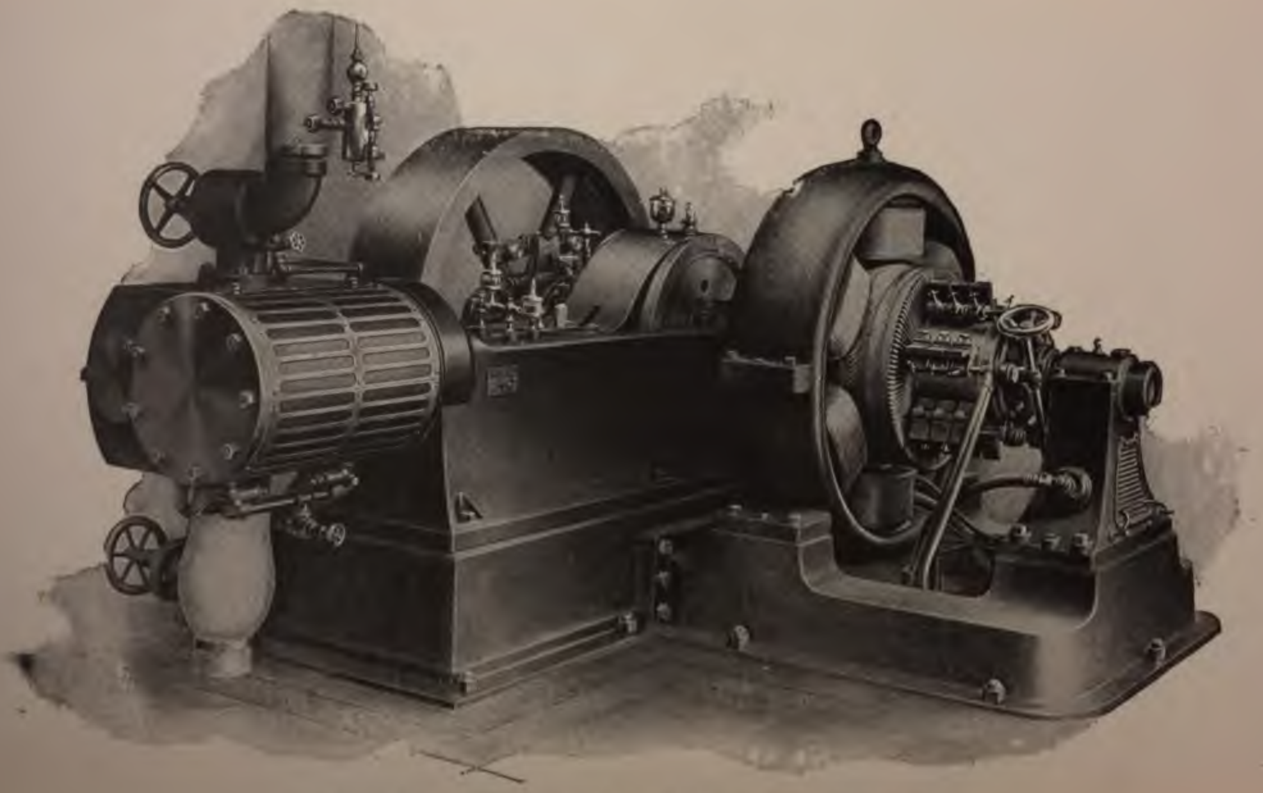


HORIZONTAL ENGINE DIRECT-CONNECTED TO GENERATOR.

New York Safety Steam Power Company.

DIRECT CURRENT DYNAMOS.

Having become familiar with some of the fundamental principles and laws governing the operation of a dynamo by a study of electro-magnetic induction, one is prepared for a more detailed study of the machine. The three important types of dynamos, the series, the shunt and the compound, have already been briefly explained, but will now be considered more in detail, and their properties will be more fully explained and illustrated by diagrams.

All of the important parts of the dynamo, such as the armature, the commutator, the brushes and brush-holders, and the field will now be treated separately and in detail.

In general, dynamos are used to furnish either light, heat or power. A dynamo receives at the pulley a certain amount of mechanical energy, which it transforms into electrical energy and delivers through the circuits with which it is connected. The power in a circuit is equal to the product of the difference of potential, E, between the terminals of the dynamo and the current, I, flowing in the circuit, or $E\,I$. When this product, $E I$, is great, a large amount of work is expended in the circuit, and to express this fact it is said that a heavy load has been put upon the dynamo. The value of $E\,I$ is increased by increasing either E or I, or both; that is, the load on the dynamo is increased when a larger current comes from it, or when the same current flows, but at a higher voltage.

We have seen that electrical power is measured in units, to which the name **watt** is given, a watt being the power of 1 ampere under a pressure of 1 volt; the product of the number of amperes and the voltage of a circuit is therefore its power. A dynamo which maintains a difference of potential between its terminals of 10 volts, and which delivers through the circuit connected with its terminals 5 amperes of current, is furnishing energy at the rate of 50 watts. Had this same dynamo been working at a difference of potential or pressure of 25 volts, and had it been delivering only 2 amperes in the circuit, it would have still been working at the rate of 50 watts. It makes no difference in the amount of power what the pressure or the current is, as long as they are of such magnitudes that their product remains the same; the dynamo will then furnish the same amount of energy per unit of time, and consequently it will take the same pull on the belt, and the same effort in the engine to drive it.

These considerations suggest two methods for distributing power and light. The necessary condition of supply is that the dynamo must be ready to meet a demand which varies between certain limits. This may be done by causing the dynamo to keep the voltage at its terminals constant at all times, and to vary the current according to the demand; or the dynamo may keep the current supplied constant, and vary the voltage at its terminals according to the demand for energy. It will make no difference to the driving power which is done. It has, however, for many reasons, been found most convenient to supply incandescent lighting systems by the first method, and arc lighting systems by the second. Power distribution has occasionally been accomplished by the second method, but the first is generally used.

In the study of **Direct Current Dynamos** it will therefore be of advantage to divide the subject into two parts: (1) Constant Potential Dynamos, machines that supply current at a constant pressure for all loads; and (2) Constant Current Dynamos, machines that supply a current of constant strength for all loads.

By having more lamps or running more motors on the circuit we increase $E\,I$, or the load upon the dynamo. In constant potential machines, E remains constant for any change in the number of lamps or motors on the circuit, within the limits of the capacity of the machine; hence, to increase the load on the dynamo, I must be increased, and it is seen readily enough that the load is proportional to I if E remains constant, or since I is inversely proportional to R, the resistance of the circuit, the load on a constant potential machine is inversely proportional to the resistance of the circuit.

In a constant current machine I is constant and E must be increased if $E I$, the load, is to increase. If E rises, and I remains the same, then R must increase according to Ohm's law. Hence the load on a constant current machine is proportional to E and to R. An increased load on constant current machines requires larger values of E and R; on constant potential machines it requires a larger value of I and a smaller value of R.

If E is to remain constant, the magnetization produced by the field coils must remain constant, or, in other words, the conductors on the armature must cut the same number of magnetic lines of force each second. If I is to remain constant and E is to increase, then a correspondingly greater number of lines of force must be cut each second.

The essential difference between the two types of machines then is that in one there is a nearly constant magnetic flux for all loads, and in the other there is a magnetic flux varying with the load. The two types of constant potential and constant current dynamos will be considered separately.

Characteristic Curves. A characteristic curve, as its name indicates, is one which shows the characteristics or peculiarities of the dynamo to which it belongs. Such a curve is obtained by plotting the corresponding values of volts and amperes of the dynamo at different loads. The data for such a curve are obtained by taking simultaneous readings of current and voltage at various loads while the dynamo is in operation. Upon a piece of cross-section paper the amperes are plotted as abscissæ and the volts as ordinates; that is, the number of amperes of one reading are laid off horizontally from the lower left-hand corner, called the origin, covering as many divisions as there are amperes; and from this point a distance is laid off vertically, covering as many divisions as there are volts corresponding to that number of amperes. The point thus obtained is a point on the curve. The remaining readings are laid off in like manner, obtaining a number of points; a smooth curve through these points gives the desired characteristic.

A number of very important properties of a dynamo may be shown by means of the **characteristic curves.** These same characteristics may generally be figured out mathematically, but it is more correct and more satisfactory to get at the results from a practical test of the finished machine, as a general rule. These characteristic curves explain the actions and possibilities of a dynamo in very much the same way that the indicator card of a steam engine gives its desired information. By drawing the characteristic curves to some known scale, the horse-power at which the dynamo will work with the greatest efficiency can be calculated.

Having drawn the characteristic curve of a machine to some particular scale, and knowing either the current, *I*, or voltage, *E*, at which the dynamo is working, the other value may be read off the curve directly. The value of the current, multiplied by the corresponding voltage, gives the output of the machine in watts, and this divided by 746, the number of watts corresponding to 1 horse-power, gives the output of the machine in horse-power.

It is possible to plot horse-power curves on the same paper with the characteristic curve (see Fig. 3), since horse-power $= \frac{\text{volts} \times \text{amperes}}{746}$. Any combination of amperes × volts which will give 746 is equal to 1 horse-power; thus 74.6 amp. × 10 volts = 1 horse-power. Evidently, then, there is an infinite number of points the product of whose co-ordinates equals 746, and a line drawn through these points is a curve of 1 horse-power. If the characteristic of the dynamo cuts the curve at any point, it means that at that point the dynamo is furnishing 1 horse-power of electrical energy. It follows at once that curves may be similarly drawn for 2, 3, 4, or any number of horse-power. Then a glance at the characteristic curve will reveal at once what the activity of the dynamo is.

THE SERIES DYNAMO.

After the invention of the magneto machine with its permanent steel magnet, it was not a very great step to put coils of wire on the field magnets, and cause the current, as it comes from the armature, to pass through them before being led to the outside circuit, thus obtaining self-excitation (see Fig. 1).

A machine so connected is called a **series dynamo** because all its conducting parts are in series with one another. The properties of this machine can be best explained by considering its characteristic curve. Every individual machine will of course have a curve differing somewhat from those of other machines which are differently proportioned, but the same general features will be present in the curve of all series dynamos. There are three characteristic curves possible for every dynamo, the **external,** the **internal** and the **total.** The distinction is as follows: the electromotive force generated by the machine is used up in two ways; in forcing the current through the resistance of the outside circuit, and in forcing it through the internal resistances of the dynamo itself. Therefore the voltage measured by a voltmeter applied to the terminals of the dynamo is the voltage which is forcing the current through the outside circuit. This voltage is given by the lower curve in Fig. 2, which is called the **external characteristic.** To get the total electromotive force generated by the machine it is necessary to multiply the current by the internal resistance and add the result to the voltage measured at the terminals. The upper curve in Fig. 2 gives the total E. M. F. and is called the total characteristic. A characteristic curve is external, internal, or total according as the volts plotted against the amperes are the volts measured at the terminals, the volts lost in the armature, or the total volts. From the series characteristic curve shown in Fig. 2 it is evident that when the circuit is open and there is no current, there is no voltage generated by the machine. With the current equal to zero, the strength of the field due to the field magnets is zero. Were there any permanent magnetism remaining in the iron as there generally is, there would be a slight electromotive force generated, and the curve would

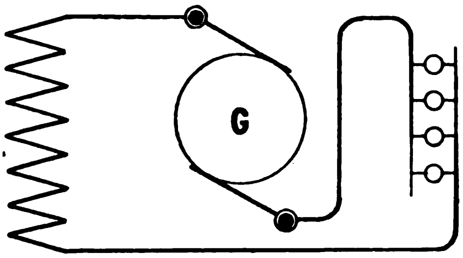


Fig. 1. Diagram of Series-Wound Dynamo.

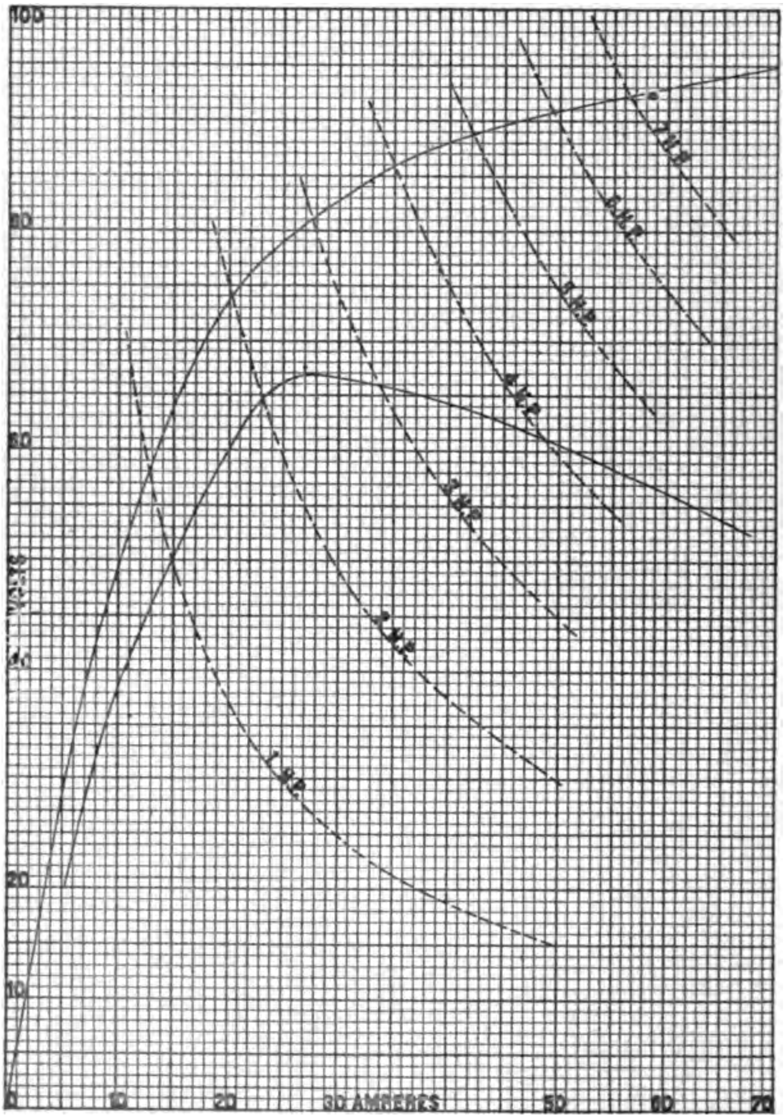


Fig. 2. External and Total Characteristic Curves of Series Dynamos.

not start at zero but a little way up on the scale. A dynamo with no magnetism whatever could not be made to take a load, or *build itself up* as the action is called. The curve runs up very steeply and approximately in a straight line, since the field, and consequently the electromotive force, increases with the increase in the current. This action goes on until the iron approaches saturation, or the point where it cannot take up any more magnetism. As it nears this point the curve bends over more and more, though still rising, until the actual point of saturation is reached. Beyond this point any increase in current cannot increase the strength of the field much and another factor becomes of importance, namely, the armature reaction. The increase in current must of course increase the armature field which tends to weaken the field due to the field magnets and consequently the voltage of the machine. It should be understood that the field of the armature does not actually exist because it is overpowered by the field magnets; it would exist were the field magnets absent and the current maintained by some external means. Its effect is to distort and weaken the field due to the field magnets. Beyond the saturation point therefore, any increase in current cuts down the field and consequently the electromotive force generated in the armature, provided the speed remains the same.

There is a very interesting property of series dynamos, which is best explained in connection with the characteristic curve. There is for every series dynamo a certain value of the current called the *critical current* at which the machine is unstable. Any increase in the circuit resistance tending to decrease the current below this value will result in the complete *unbuilding* of the machine and the consequent loss of load. Similarly the machine will not take a load or *build up* unless the resistance of the circuit is low enough so that the current can reach the critical value.

An examination of the characteristic curve shows that at a point a little more than two thirds of the way up to the maximum value of the curve, any decrease in the current of the machine decreases the voltage much more rapidly than is the case at any point higher up. This large decrease in voltage still further decreases the current, which result reacts on the voltage again, and this process goes on until the machine is completely unbuilt.

Total and external characteristic curves of a small Wood arc light dynamo are shown in Fig. 3. The total voltage generated by the armature is equal to the voltage observed at the terminals plus the lost voltage of the armature and series coils.

This was calculated by the equation

$$E' = E + I\,(r_a + r_{se})$$

where r_a was 5.4 ohms and r_{se} was 6.83 ohms.

The observed voltages are corrected for a speed of 1150 revolutions.

The electrical efficiency for this machine was calculated and found as follows:

DATA FOR EFFICIENCY OF SMALL WOOD DYNAMO.

E	Speed	I	$E'\,I'$	$E\,I$	$\frac{E\,I}{E'\,I'}$
88	1150	1	100	88	88 %
298	1150	4.4	1548	1311	84.7%
310	1150	4.6	1684	1426	84.6%
372	1150	6.0	2670	2232	83.5%
402	1150	7.0	3413	2814	82 %

The usual use of the constant current dynamo is for arc lighting. Arc lamps are commonly run in series and require about 10 amperes, and a potential of about 50 volts across the terminals of each. To maintain a constant current in the circuit the E. M. F. at the brushes of the generator must then increase 50 volts as each lamp is thrown in.

Constant current dynamos are series wound. Of such machines, we know that with a variable resistance in the external circuit, the current, or E. M. F. or both will vary. In the case of a machine supplying a certain current, if the resistance is increased the current strength will fall, and the field coils being in series the magnetic field is weakened, thereby lowering the E. M. F. and still further lessening the current. On the other hand if the external resistance is reduced, a larger current flows and a correspondingly higher potential is generated. Obviously, if such a machine is required to give a constant current through a

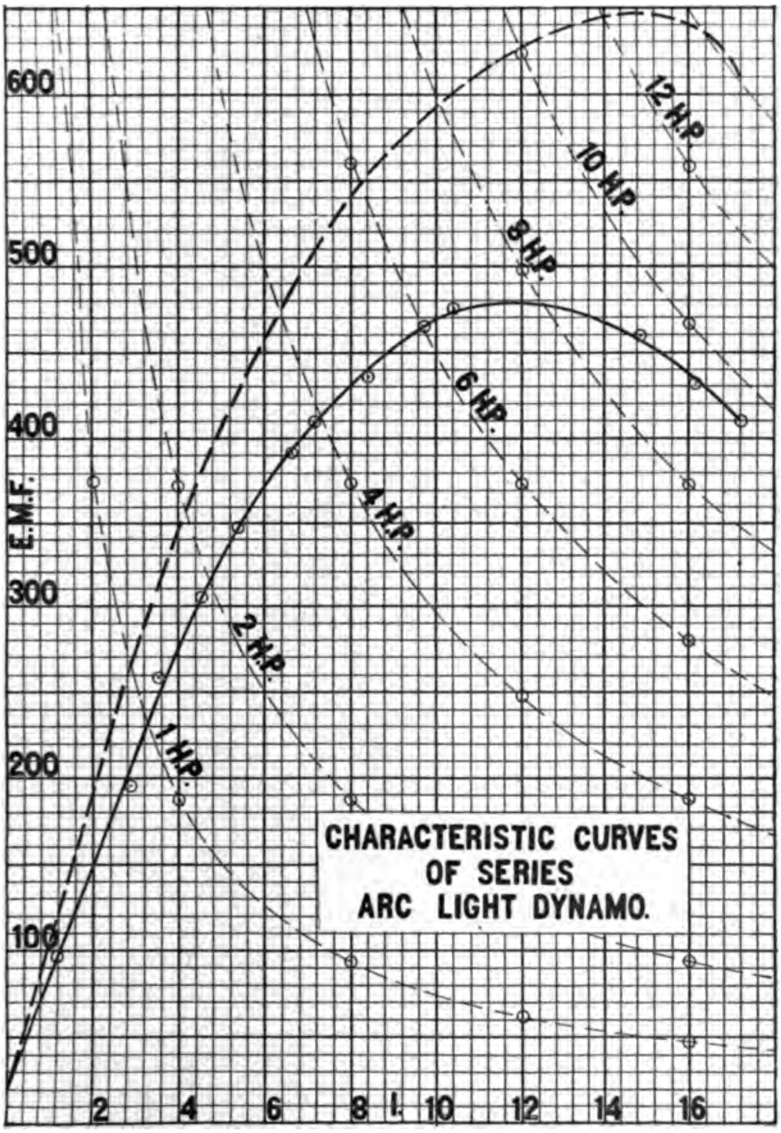

600
500
400
300
200
100
E.M.F.
2
4
6
8
I.
10
12
14
16
1 H.P.
2 H.P.
4 H.P.
6 H.P.
8 H.P.
10 H.P.
12 H.P.
CHARACTERISTIC CURVES
OF SERIES
ARC LIGHT DYNAMO.

Fig. 3.

variable resistance, there must be some means provided for raising and lowering the E. M. F.

For effecting such regulation there are these three methods: (1) Varying the speed. (2) Varying the field strength. (3) Changing the position of the brushes.

The first method is seldom made use of although in principle it is very simple. There must be an automatic regulation of speed and the E. M. F. of course rises and falls with it. Such regulation, on account of the inertia of the heavy moving parts of the engine and generator, is too slow for lighting service.

Regulation by the second method is obtained either by changing the number of active conductors in the field or by changing the connections of the coils from series to parallel and *vice versa.* Running on light load (few lamps in series) only enough turns in the field are left in circuit to maintain a current of 10 amperes, and as more lamps are added to the circuit more field turns are thrown in to strengthen the field and to raise the voltage. The disadvantage of this method is the small range of loads that can be economically carried. For as the field coils are thrown in the cores soon rapidly approach the point of saturation, beyond which a large increase of ampere-turns effects the E. M. F. very slightly. On the other hand the machine will not run well on very light loads, for the current being constant the reaction of the armature is constant and on the weakened field has a greatly increased effect of distortion upon the field and causes serious sparking at the brushes.

The third method, that of shifting the brushes, is the most common one. To understand the principle of this regulation it will be well to refer back to the figure showing the two paths of the current through a ring armature and out by the brushes (see illustration in section devoted to "Theory of Dynamo-Electric Machinery"). It will be seen readily that the maximum E. M. F. at the brushes is obtainable when they are at the neutral point, that is when all the amature coils on either side of the brushes generate an E. M. F. in the same direction. If the brushes are shifted from the neutral point then some of the coils on either side oppose the others on the same side and a reduced pressure at the brushes is the result. If the brushes were placed at points midway between the neutral points, then on each side half the coils would oppose the other half, and the pressure at the brushes would be nil; that is, the algebraic sum of the E. M. F.'s of the coils in each half would be zero. Then by moving the brushes from this point toward the neutral point, this sum, or the E. M. F. of the machine, would increase gradually to the maximum. Such is the principle of this method of regulation.

A constant current machine running on light load will have its brushes in a position considerably off the neutral point, and as more lights are thrown into the circuit, making the load heavier, they will be brought correspondingly nearer, maintaining sufficient E. M. F. at the brushes to force a current of constant value through the increasing external resistance. The shifting of the brushes is done automatically by electro-magnets in circuit, which act instantly to counteract any change of current strength flowing through them.

In practice various devices are used by different makers to accomplish the regulation. In some machines the position of the brushes on the commutator is altered by a mechanism controlled by the current; in others the controlling mechanism alters the field strength by short-circuiting some of the coils, or by increasing or decreasing a resistance placed as a shunt around the field, thus varying the value of the current in the field coils instead of the number of turns. The variable brush method is sometimes combined with the variable field method. A description of some forms of arc lighting machines, together with their regulators, is given in a following section.

Saturation Curve. To obtain a certain magnetization by a field coil, it is immaterial whether the coil consists of a small number of turns carrying a large current, or of a large number of turns carrying only a small current. As long as the product of the number of turns and amperes passing in them, or **ampere-turns**, is the same, the magnetization produced will be of constant value. Thus a coil of 100 ampere-turns may be made up of one turn of a large heavy wire carrying 100 amperes, or it may be made up of 100 turns of fine wire carrying one ampere, and the magnetizing force which will be exerted will be exactly the same in either case. Magnetizing forces are therefore sufficiently expressed by the number of ampere-turns in the magnetizing coil.

The saturation curve of a dynamo shows to what intensity the field magnets have been magnetized, and thus whether they are properly designed. The curves are formed by plotting points whose abscissæ are values of ampere-turns in the field coils, and whose ordinates are the corresponding values of the voltage, these points being plotted for varying values of the current. The readings may be observed for both ascending and descending values of the current, thus showing the effects of hysteresis.

From an economical standpoint it is best not to carry the magnetic flux too near the point of saturation during normal working, for the number of ampere-turns required to produce a given magnetic flux is greater in a saturated field than in one not saturated. In certain types of machines, however, there are certain advantages in practical points of working and regulation to be derived from having saturated fields that are of such importance as to outweigh the value of greater efficiency. By knowing from the type and the design of a machine to what degree its fields should be saturated, and by having an experimental saturation curve of the machine, a comparison can be made between the ideal and the result. Fig. 4 gives the saturation curves of the magnetic circuit of a Crocker-Wheeler dynamo for no load and with load, and for increasing and decreasing values of the current, the dynamo running at a constant speed of 1,620 revolutions per minute. The total characteristic curve of the simple series dynamo is only a slightly modified saturation curve, as will be seen from a comparison of Fig. 2 and Fig. 4. But in dynamos provided with regulators, the operation of these appliances changes the form of the characteristic very markedly.

THE SHUNT DYNAMO.

The shunt dynamo is so named because the coils which excite the field, instead of being connected in series with the outside circuit, form a shunt about it, the field circuit and outside circuit being connected in parallel at the brushes (see Fig. 5).

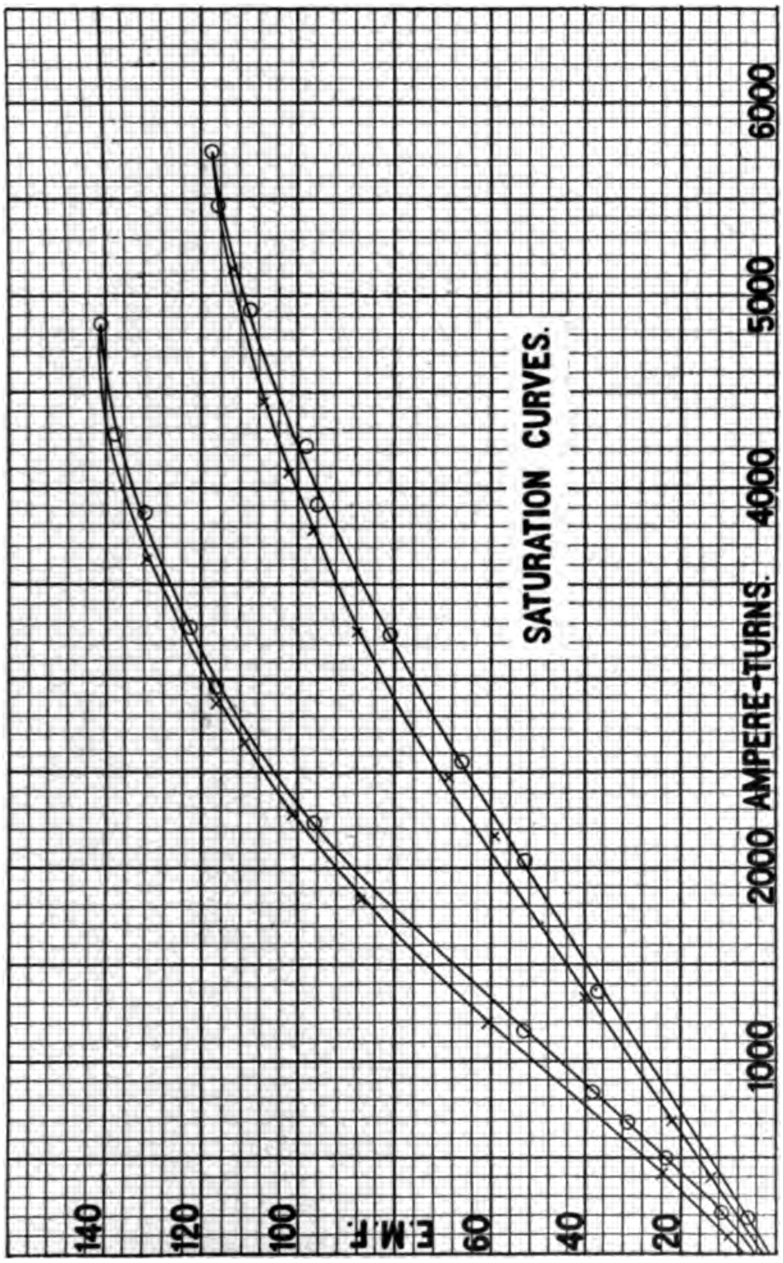

SATURATION CURVES.
AMPERE-TURNS.
1000
2000
4000
5000
6000
E.M.F.
20
40
60
100
120
140

Fig. 4.

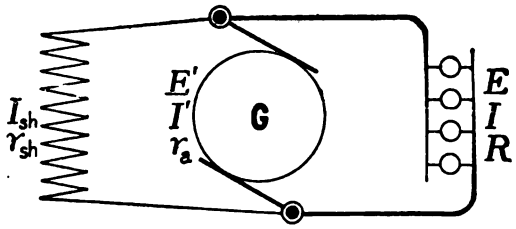


Fig. 5. Diagram of Shunt-Wound Dynamo.

As in the case of the series dynamo, the properties of the shunt machine can be best explained with the aid of characteristic curves (see Fig. 6). There are three characteristic curves to be considered, the **external,** in which the volts at the terminals are plotted against the amperes in the outside circuit, the **internal,** in which the volts at the terminals are plotted against the amperes in the shunt circuit, and the **total** in which the total volts generated by the machine are plotted against the total current. The total characteristic differs from the external only in that the volts are obtained by adding to the volts at the brushes the drop in potential through the armature. This drop in volts is equal to the current passing in the armature multiplied by the armature resistance. The total current is obtained by adding the current in the shunt circuit to that in the outside circuit. The internal characteristic taken with the outside circuit open is like the curve for a series dynamo. It rises steeply at first and then bends over as the saturation of the magnets begins to be noticeable. In fact with the outside circuit open the machine is a series dynamo with all its circuit in the field coils.

The external characteristic curve is a loop. It begins at maximum voltage and zero current, and extends almost horizontally at first, then slopes down more and more, turns rather suddenly, then doubles back and tends to approach the origin. When the dynamo is started the outside circuit is open and there is no current through the armature. As soon as it is built up the armature is generating only the current for the field coils which, as we have seen, is very small owing to the great resistance of these coils. But the small current produces only an insignificant drop in the armature so that the voltage at the brushes is nearly the total generated by the armature. Hence the current in the field coils is as great as it can ever become which makes the field magnetism and consequently the E. M. F. generated by the armature a maximum. Now suppose that a number of lamps (connected in

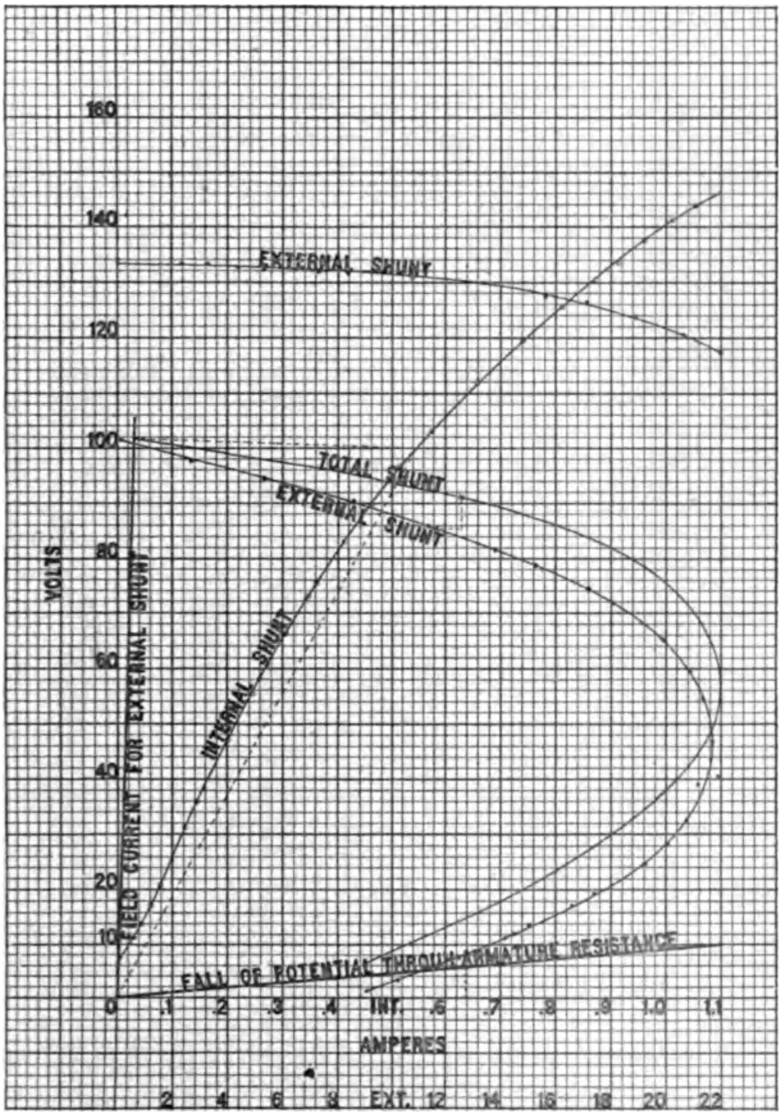
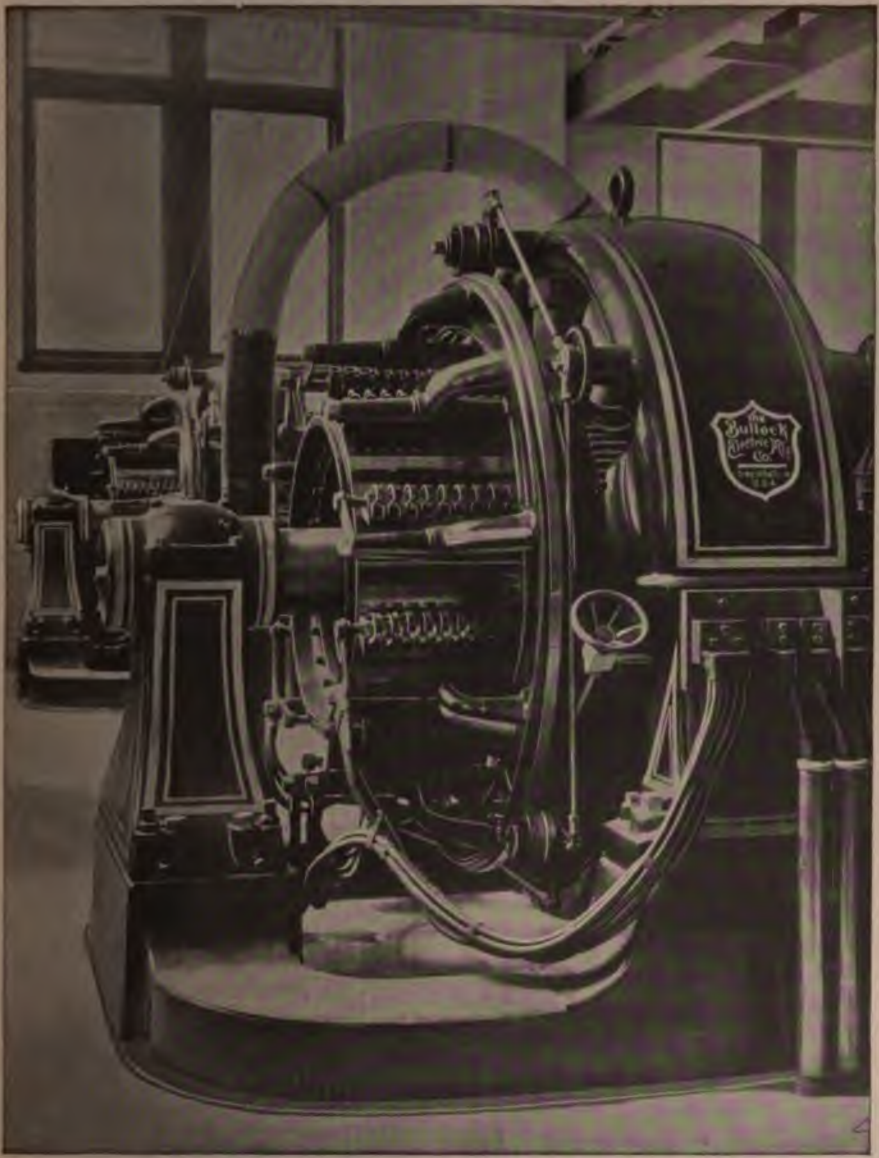


Fig. 6. **Total. External and Internal Characteristic Curves of Shunt Dynamo.**

parallel across the leads from the machine) are thrown on the machine. A current flows at once, and as a result there is a drop through the armature so that there is a little less voltage available at the brushes to excite the field coils, which means a slight dropping of the total voltage. If more lamps are connected in parallel, the existing voltage at the terminals will act for an instant, and furnish them with as much current as those already on are receiving, but the greater current means increased drop in the armature which, as explained above will again bring down the total voltage generated. With less voltage at the terminals the total current will diminish a little. Therefore lowering the resistance of the circuit by the addition of lamps in parallel lowers the available voltage, because it increases the amount of the volts lost in the armature. By building the armatures with an extremely low resistance it is possible to make machines for which the drop in terminal pressure is not very noticeable over quite a large range of load. It is for this reason that a shunt machine is used for incandescent lighting where it supplies an approximately constant voltage. The dynamo would be designed for such a voltage that at low loads the voltage would be a little too high while at heavy loads it would be a little too low. In actual lighting work, however, the resistance of the field coils is made somewhat less than would be necessary to give the right voltage. This is accomplished by using a larger size of wire than necessary, the number of turns remaining the same.

By inserting a **rheostat,** or resistance which can be varied at will, between the field coil and one of the brushes, the current in the coil can be cut down to the proper value under normal conditions, and when the load increases and the effective voltage tends to drop, it is only necessary to cut out some of the resistance in the rheostat to obtain more current, and consequently greater excitation in the field coil, thereby raising the voltage to its normal value again. The rheostat (see Fig. 7) consists generally of a resistance with connections at short intervals along it and terminating in metal contacts arranged in a circle. A sliding contact piece is moved over them by the handle, introducing the current at any point on which the sliding contact is resting. In this way the amount of resistance in series with the field coil may be regulated with great exactness.



250 K.W. ENGINE-TYPE GENERATOR
at Prudential Life Building, Newark, N. J.
Bullock Electric Manufacturing Co.

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ASTOR, LENOX
TILDEN FOUNDATIONS

This regulation is generally effected by hand, the resistance being decreased when the voltmeter shows that the voltage is falling on the line, and vice versa. By means of regulators, magnets, solenoids and various electrical and mechanical means this regulation is sometimes made automatic.

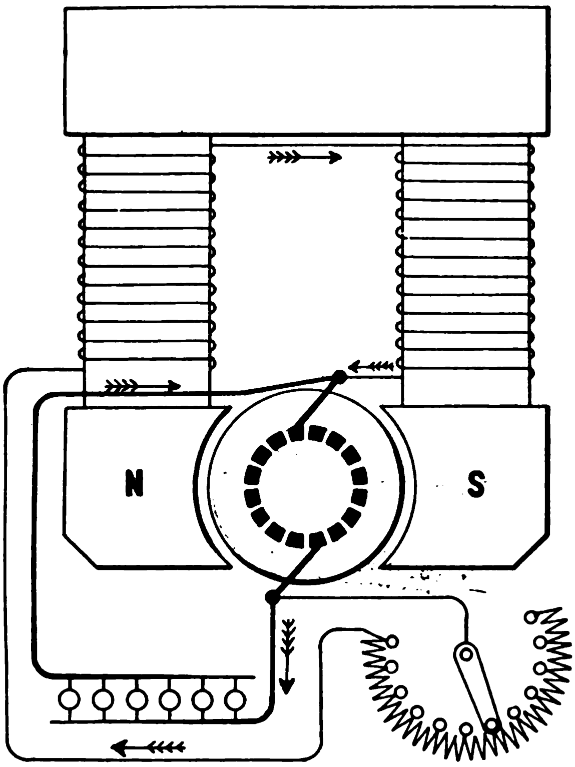

Fig. 7. Dynamo and Rheostat.

Returning to the characteristic, it is interesting to note that the continued increase in load on the machine, due to decrease of external resistance, causes the voltage to fall more and more rapidly until a point is reached where a decrease in circuit resistance can throw no more load on the machine, because the decrease in voltage is so rapid as to unbuild the machine. Theoretically the curve would come down to the origin; it does not, practically, however, owing to residual magnetism.

The resistance of the outside circuit corresponding to any point on the characteristic curve can be found very readily. The voltage divided by the current gives the resistance. By drawing a straight line (see Fig. 8) from the origin or the point where the current and voltage are 0 through the point corresponding to 50 volts and 50 amperes it will intersect the characteristic curve at a certain point. It is obvious from the figure that the voltage at this point just equals the current, and so the resistance here is 1 ohm. Similarly by drawing a line from the origin through the point where voltage is 100 and current 50 the characteristic curve is intersected at another point and the resistance of the circuit at this point is 2 ohms. A scale of resistance may be marked on the vertical line corresponding to 10 amperes. By drawing a line from any point on the characteristic curve to 0, the point of intersection on this resistance scale line gives the resistance of the outside circuit. The characteristic curve shown in Fig. 6 is for a small shunt dynamo which being run at 630 revolutions gave a maximum of a little less than 2 horse-power at 68 volts and 19.2 amperes. With a decrease in resistance much below $2\frac{1}{2}$ ohms the current increases but little, whereas the voltage falls a great deal. If the external resistance becomes less than 1 ohm the machine loses its voltage and current immediately and will not build itself up again until the resistance is increased. The most critical part of this curve is where the voltage is about 30 or 31 and any given change of resistance at this point will alter the voltage more than at any other part of the curve. By increasing the resistance the voltage is steadily increased until it gets to its maximum when the external circuit is open and the resistance is infinite, the whole voltage being then available for magnetizing the shunt field coils to their maximum strength.

Fig. 8 shows the characteristic curves of a shunt-wound Gramme dynamo capable of giving 400 amperes at 120 volts. The armature conductors were not capable of carrying more than 400 amperes, and the part of the curves not actually found by experiment is shown in dotted lines. The lower curve marked *E* is the external characteristic while the upper curve marked *E'* is formed from it by adding to the external voltage at any point the corresponding value of the voltage lost in the armature at the given time.

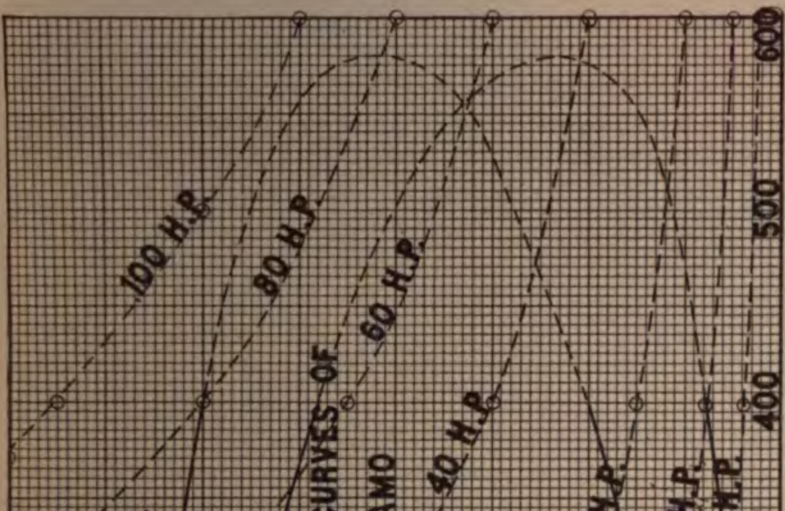

Fig. 8. Characteristic Curves of Shunt-Wound Gramme Dynamo.

Both series and shunt machines have critical points, but the series machine will act only with the resistance of the circuit less than a certain amount while the shunt machine will work only with it greater than a certain amount. With the series machine, increase in the number of lamps in series decreases the ability of the machine to maintain its load, increase in the number of lamps in parallel increases the ability of the machine to generate and consequently increases the current per lamp. With the shunt machine an increase of the lamps in series increases the ability of the machine to furnish current, while increase in the number of lamps in parallel decreases the ability of the machine to supply current. These opposing characteristic qualities are made use of to secure a machine which is automatic in its ability to furnish a constant potential under widely varying loads.

THE COMPOUND DYNAMO.

Electrical energy for incandescent lights, power circuits, and railways is supplied by constant potential dynamos, that is by machines which are so constructed that they will deliver current varying in amount between zero and the limit of their capacity and at the same time maintain a pressure at the terminals that is very nearly uniform.

Though a shunt machine comes nearer to fullfilling the requisite conditions than a series, still neither are self-regulating. The shunt machine with a variable resistance in series with the field coils, has been used as described on a previous page. There are also other arrangements which could be used to attain the same end but as they have not found favor in practice they will not be considered here.

It has been shown how with the shunt machine, owing to increase in current, the volts lost in the armature are increased, resulting in decreased ability to sustain the output. To make a shunt machine self-regulating some means must be provided for increasing the field strength with the increase of the strength of the current. This can be easily accomplished by winding on the field magnets a coil consisting of a few turns of heavy wire through which the whole current of the circuit can be passed. This series coil is sometimes called the compensating coil because it compensates for the weakening tendency when the shunt coil alone is used. A machine with such a winding is called a **compound-wound machine.** Being a combination of the series and shunt machines, its characteristic curve is a combination of the two, the rise in the characteristic of the series machine occurring at the point where that of the shunt machine decreases.

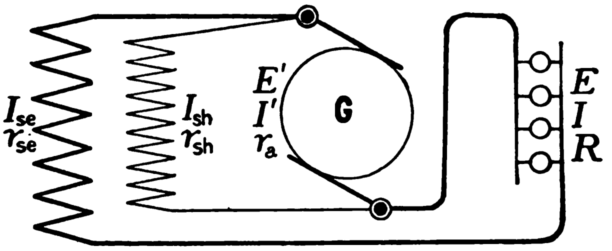

Fig. 9. Ordinary, or Short Shunt Compound Dynamo.

There are two methods of connecting up a compound-wound machine, called respectively **short shunt** (see Fig. 9) and **long shunt** (see Fig. 10), according as the shunt terminals include the armature, that is, connected from brush to brush, or the series coil in addition, that is, connected from brush to end of series coil. It makes very little difference in practical results which form of connection is employed, since the resistance of the series coils is always very small. The characteristic curve of a compound machine generally approaches a horizontal line, often it rises slightly at the beginning and then continues nearly horizontal throughout the range of loads that it is required to carry.

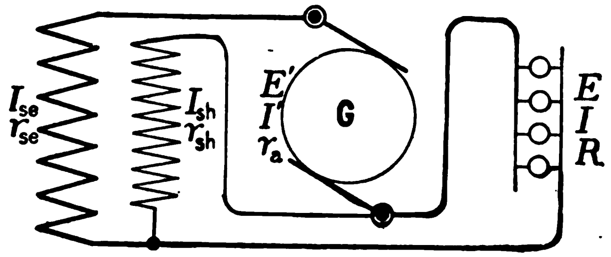

Fig. 10. Long Shunt Compound Dynamo.

As the load increases and the resistance of the outside circuit decreases the main current in the series field coils increases and the current in the shunt coils still remains constant as it is now fed with a constant voltage. Thus although there are more lost volts in the armature to cut down the voltage, and although there is a much greater demagnetizing effect produced by the armature yet the voltage supplied to the external circuit is still maintained constant. A compound dynamo therefore if properly proportioned, will supply a practically constant voltage at all loads. In the case of the ordinary or short shunt compound dynamo, the potential at the brushes is kept constant. In the case of the long shunt dynamo the potential at the terminal of the working circuit is constant. The latter arrangement therefore is somewhat preferable but either arrangement proves satisfactory in well designed dynamos as the actual value of the difference in the two cases is generally very slight.

In the case of the ordinary or short shunt compound dynamo the series coils furnish the excitation required to produce a potential such as will compensate for the lost voltage in the armature and the demagnetizing effects due to the armature. In the case of the long shunt dynamo the series coils compensate for these same losses as well as for the lost voltage of the series coils.

It is advisable and generally customary to put a somewhat greater number of series turns on the field coils than is necessary to overcome armature reactions and lost voltage in order to have the dynamo give a somewhat greater voltage at full load than at no load. This process which is called **overcompounding** is calculated for a rise of voltage of about four or five per cent. As the load increases an engine often runs a few revolutions slower, or there is a trifle more slipping of the belt which causes the speed of the armature to drop a little; the increasing load is also accompanied by a greater lost voltage in the line or feeders; hence the dynamo should be overcompounded to make up for these losses. If the load is at some distance from the generator there might be considerably more than 5% drop of voltage at full load. This drop can be figured and a machine may be especially compounded for this loss at the time it is built. The object of course is to keep the voltage constant at the lamps, and if they are some distance away and the load is constantly changing it is often necessary and advisable to run so-called *pressure wires* from the center of distribution back to a voltmeter in the dynamo room. Then if the dynamo is not overcompounded so as to give the proper pressure at all loads the pressure may be varied by adjusting the rheostat which is in series with the shunt coils of the dynamo. Even though the dynamo is properly compounded it is almost always necessary to regulate with the rheostat also in the case of incandescent lighting, especially where the lamps are distributed over a wide territory.

In designing a dynamo for any given output it is necessary to make due allowance for the total energy to be generated which is the total voltage E' multiplied by the total current I'. In order that the energy lost in the series field turns may not be too great, it is well to have them wound near the field cores so that each turn may be as short as possible and the shunt coils may be wound outside of the series turns.

In Fig. 11 are shown some characteristic curves of a compound-wound Crocker-Wheeler dynamo running at 1500 revolutions per minute.

The upper curve is the external characteristic of the dynamo running with all the resistance cut out of the shunt field regulating rheostat. It is running, therefore, with a maximum field excitation and giving its maximum voltage, about 127.8 volts at no load. It will be noted that as the load increases the voltage drops somewhat. It is evident that the magnetic flux due to the series ampere-turns on the field coil is not great enough to make up for the armature demagnetizing effects and the lost volts in the armature. Therefore there are not enough series turns, and the dynamo is undercompounded when running at 127.8 volts.

Next some of the resistance of the regulating rheostat is put in series with the shunt field until the voltage falls to 109.2 volts. By increasing the load the voltage increases, being from about 4% to 7% higher as the load increases than it was at no load. Now the rise in voltage, due to compounding, makes up for the loss in the line wires and is a little too great in the case of the 7%, and in order to keep the lamps from burning too brightly the rheostat handle would have to be turned so as to cut the voltage down a little.

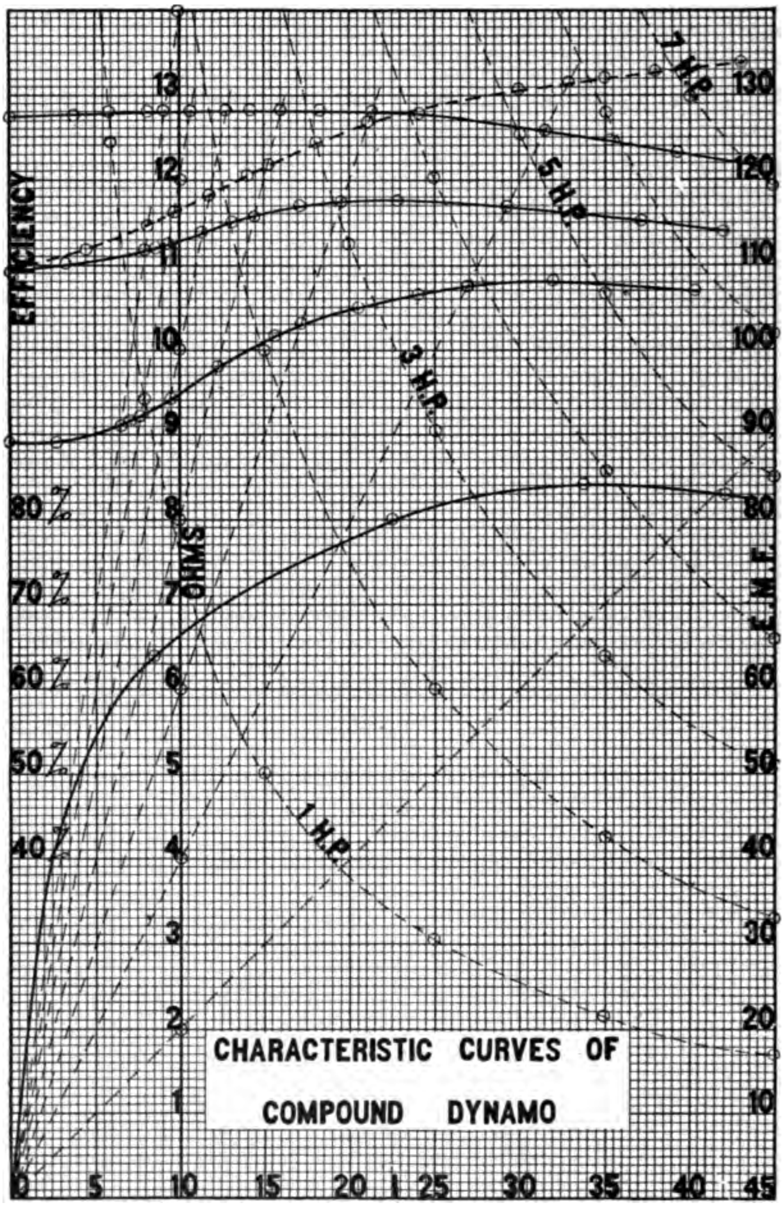

Fig. 11. Characteristic Curves and Efficiency Curve of a Crocker-Wheeler Compound Dynamo.

Judging from these two curves it appears that if the dynamo were run at a little higher initial voltage, say 112 or 115 it would be then running at just about the proper voltage for which it was compounded. The percentage of the overcompounding would then be about four or five per cent and the dynamo might run at varying loads with little or no need of adjusting the rheostat.

The curve shown by broken line (see Fig. 11) is the total characteristic curve derived by adding the values of the lost volts in armature and in series field to the value of the external voltage.

The lower compound characteristic curve starting with an initial voltage of 89 shows that the dynamo is very much overcompounded when running at this voltage. The rheostat has been so adjusted that less current flows through the field coils, the shunt current is reduced and the value of the shunt ampere-turns is reduced. On the other hand the value of the series ampere-turns is as great as formerly as the load increases, and so the value of the series excitation is now large in comparison with that of the shunt. The voltage therefore increases greatly with the load, causing the dynamo to be greatly overcompounded when started at an initial voltage of 89.

In Fig. 11, is also given a curve of commercial efficiency for this 5 H. P. Crocker-Wheeler compound dynamo, the commercial efficiency being the useful electrical work, *E I*, derived from the dynamo, divided by the value of the mechanical work delivered to the pulley of the dynamo.

The following table contains the data from which the characteristic curves shown in Fig. 11 were drawn.

I	E	I	E	I	E
0	127.8	0	109.2	0	89.
3.6	128.0	3.4	110.0	2.7	89.1
8.4	128.0	8.7	112.0	7.2	91.3
14.2	127.7	13.2	115.0	11.3	96.4
18.4	127.7	17.1	117.0	15.6	101.8
23.8	127.6	22.6	117.0	20.6	105.0
27.2	127.2	25.6	116.8	24.6	105.4
30.9	126.0	29.3	116.0	27.9	107.5
35.2	124.0	33.7	116.0	32.0	108.2
39.3	122.9	37.1	115.9	36.1	108.0
43.8	121.9	42.8	114.0	40.3	107.0
				40.4	107.0

The characteristic curves of a 5 K.W. Edison compound

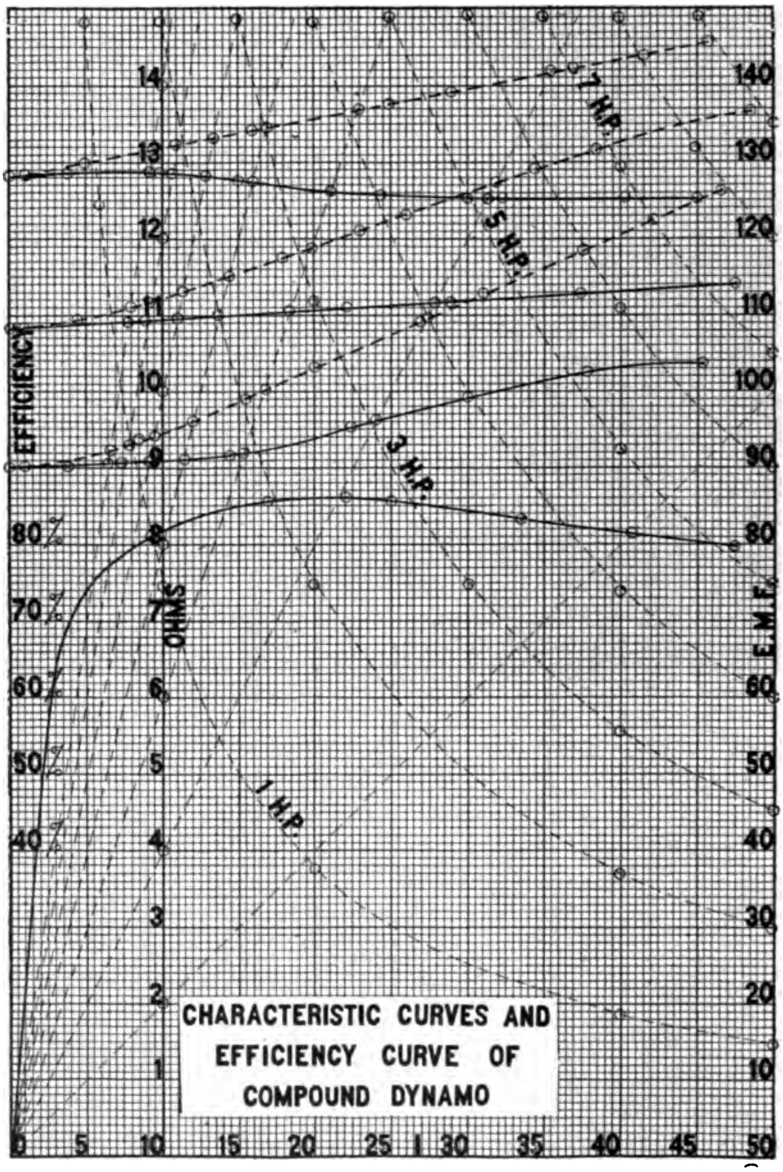

Fig. 12. Total and External Characteristic Curves and Efficiency Curve of 5 K.W. Compound Edison Dynamo.

dynamo are given in Fig. 12, for initial voltages of 131, 110, and 90, at a speed of 1,700 revolutions. In testing dynamos it is very difficult to keep the speed absolutely constant. There may be a variation in the speed of the main pulley from which the dynamo is run, and the belt may slip more and more as the load increases. However, as the voltage is proportional to the speed, the observed voltage may be corrected for the observed speed quite readily. The reading of the voltmeter and the tachometer should both be taken at the same instant.

The characteristics of the compound Edison dynamo as shown in Fig. 12, present very much the same phenomena as were exhibited by the characteristics of the Crocker-Wheeler dynamo in Fig. 11. The Edison dynamo, the curves of which are shown, is probably properly overcompounded for about 4% or 5% when running at an initial voltage of about 115. A curve of electrical efficiency is also shown.

The following table gives the data for the characteristic and efficiency curves of the 5 KW. compound Edison dynamo.

Speed.	E	E corrected to 1,700 rev.	I	Speed.	E	Corrected E	I	$\frac{E\ I}{E'I'}$
1740	131.5	128	0	1720	110	108.1	0	0
1725	130.0	128.1	3.8	1715	111	109.3	8.7	.82
1730	130.0	128.3	9.8	1690	111	111.0	22.0	.86
1725	128.5	126.7	14.7	1670	110	111.3	28.7	.87
1720	128.0	126.6	19.2	1665	112	113.1	37.3	.82
1715	126.5	125.4	24.3	1660	112	114.0	47.5	.80
1710	126.5	125.6	28.0	1730	91.5	90.0	.0	
1705	125.5	125.3	32.2	1730	91.5	90.0	7.4	
1685	124.0	125.2	36.0	1725	93.0	91.6	14.6	
1670	123.0	125.3	40.3	1715	96.5	95.7	22.4	
1665	123.0	125.6	45.0	1685	99.0	99.9	30.0	
1635	118.5	123.3	46.5	1660	99.5	101.9	38.0	
				1640	100.0	103.7	45.4	

THE MAGNETIC CIRCUIT.

Every dynamo-electric machine or electrical instrument whose working depends upon the laws of magnetic induction, must have a complete magnetic circuit just the same as it has a complete electric circuit. Moreover the laws governing the magnetic circuit are similar to the laws governing the electric circuit. The one important difference between the magnetic circuit and the electric circuit lies in the difference of materials of which the two are composed. Every substance is a conductor of electricity to a certain extent; there is no perfect non-conductor or insulator. The best conductors are metals and graphite. Dry air, dry wood, mica, rubber, etc., are such very poor conductors of electricity that they are called insulators or non-conductors.

Almost all substances are fairly good conductors of magnetism. Iron and steel in their various forms are *excellent* conductors, and nickel, cobalt and oxygen lie between these and the fairly good conductors in their magnetic qualities. Fairly good conductors include solids, liquids and gases, metals and non-metals, organic and inorganic substances; and with the exceptions named above and a few others, they are *equally* good conductors. Air is generally taken as the standard and is neither a better nor a poorer conductor than gold or copper.

The greater the current in an electric circuit the greater is the amount of energy required to cause the current to flow, provided the resistance remains unchanged. In like manner the amount of energy required to produce a magnetic flow in air is proportional to the strength of the magnetic field produced. Iron and steel however have induction coefficients which are very important in their bearings. When an electromagnet is weakly magnetized the amount of electrical energy required is nearly proportional to the strength of magnetism. After the metal begins to be **saturated** with magnetic lines, the amount of electrical energy required to increase the magnetism becomes much greater than formerly. After the metal has become strongly saturated with magnetic lines even a large increase in the electrical energy supplied may produce almost no increase in the magnetic intensity.

In order to have an electric flux or electric current in an electrical circuit it is necessary to have an electromotive force. Similarly in order to have a magnetic flux or magnetic field it is first necessary to have a **magneto-motive force,** (M. M. F.). Lodestones and other so called permanent magnets have a magneto-motive force that keeps up a magnetic flux or field constantly. By passing an electric current through an electric circuit a magneto-motive force is induced at right angles to the path of the electric conductor. In the electric circuit a given E. M. F. will cause a larger current to flow through a low resistance conductor than through a high resistance conductor. Similarly with a given M. M. F., a greater magnetic flux is produced in a good magnetic circuit of iron or steel than in a poor magnetic circuit of air or copper.

The geometrical distribution of the magnetic lines of force about a conductor carrying a current is shown in Fig. 8, which gives an end view of the conductor. The current is assumed to be flowing toward the observer, and the direction of the magnetic flux is shown by arrows. As shown by the flux paths 1, 2, 3, 4, 5, the magnetic density is greater near the wire, diminishing rapidly in strength farther from the conductor. The mathematical law of this diminution is as follows: the intensity varies inversely as the distance from the conductor.

If an electric conductor is bent into the form of a loop and an electric current of one ampere passes through the conductor then a certain number of magnetic lines of force pass through the loop. After following curved paths they will return to the loop passing through it again in the same direction as at first. Now if two amperes flow through this conductor, or the same current (one ampere) flows through two similar conductors laid side by side, then in either case just twice as many magnetic lines will flow through the loop as in the first case. Therefore the intensity of the magnetic flux through a loop composed of an electric conductor carrying a current, depends upon and is directly proportional to the number of **ampere-turns.** This magnetic flux can be made very great either by forcing a large current through the conductor, or by having a very large number of turns in the loop, or by both.

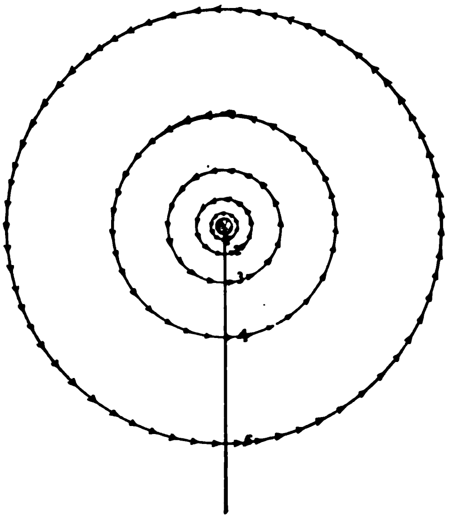

Fig. 8.

The absolute unit of current being ten times the ampere, the ampere-turn is only one tenth the value of the current-turn. Of the two, the ampere-turn is in more common use as a practical unit. The fundamental unit of M. M. F. in the United States is called the **gilbert**, and is produced by $\frac{1}{4\pi}$ of a C. G. S. unit or current-turn, or by $\frac{10}{4\pi}$ ampere-turns. Therefore by dividing the number of ampere-turns in any coil by $\frac{10}{4\pi}$, the M. M. F. of the coil is obtained in gilberts.

The quantity of magnetic flux in any magnetic circuit depends upon the M. M. F. and upon the nature and form of the circuit. In an electric circuit the current produced by an E. M. F. depends upon the resistance of the circuit. Similarly in a magnetic circuit the magnetic flux produced by a M. M. F. depends upon the **magnetic reluctance** or simply **reluctance** of the magnetic circuit. Magnetic reluctance is similar to electric resistance and is often defined as *the resistance of a circuit to magnetic flux.*

The resistance of an electric circuit measured in ohms is equal to the **specific resistance** or **resistivity** of the conductor, multiplied by the length and divided by the cross section of the wire. Similarly, the reluctance of a magnetic circuit, measured in **oersteds,** is equal to the **specific magnetic resistance** or **reluctivity** of the magnetic conductor, multiplied by its length in centimeters, and divided by its cross section in square centimeters. The reluctivity of a vacuum is unity and the reluctivity of air is generally considered equal to unity although it varies slightly. All other non-magnetic substances such as brass, copper, glass, wood, and water also have a reluctivity which is practically equal to unity. The reluctivity of magnetic metals such as iron, steel, nickel, and cobalt vary quite widely from unity and their values also vary quite widely among themselves.

The unit of reluctance by which the magnetic resistance of a circuit is measured is called an **oersted,** and is defined as the reluctance or magnetic resistance of a cubic centimeter of air measured between two opposite faces, hence the reluctance of a column of air 20 cm. long and 2 cm. square (4 sq. cm.) is 5 oersteds.

In the electric circuit,

Electric flux (in amperes) =

$$\frac{\text{Electromotive force (in volts)}}{\text{Resistance (in ohms)}}, \text{ or } I = \frac{E}{R}.$$

In the magnetic circuit,

Magnetic flux (in webers) =

$$\frac{\text{Magneto-motive force (in gilberts)}}{\text{Reluctance (in oersteds)}}, \text{ or } \Phi = \frac{\mathfrak{F}}{\mathfrak{R}}.$$

If a non-magnetic ring (see Fig.14), is uniformly wound with insulated wire, and a current is passed through the wire, the magnetic circuit will be completely closed by the coil or solenoid, and no magnetic flux will leak outside of the coil. If the cross section of the ring is 15 sq. cm., and the mean circumference is 45 cm., the reluctance of the magnetic circuit will be $\frac{45}{15} = 3$ oersteds. If the number of turns of wire is 100 and the current 5 amperes the M. M. F. in the magnetic circuit will be 500 ampere-turns, or $500 \div \frac{10}{4\pi} = 628.32$ gilberts. The magnetic flux in webers will be

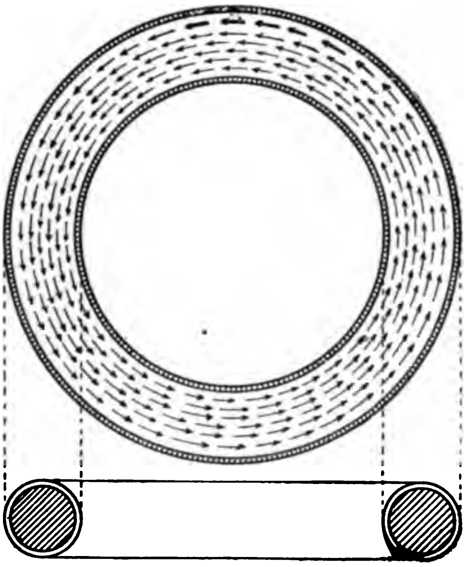

Fig.14.

$$\frac{628.32}{3} = 209.44 \text{ webers.}$$

The **weber** is the ***magnetic line*** of the preceding section.

The greater part of the magnetic circuits in dynamos consists almost entirely of iron. The reluctivity of iron and steel varies greatly, according to hardness and chemical composition, and also the degree to which it has been magnetized. When iron is fully saturated magnetically its reluctivity is as great as the reluctivity of air. The reluctivity of soft iron or steel, when it is not strongly magnetized, is often several thousand times less than that of air. The ferric magnetic circuit is an easy one to calculate, however, since the magnetism is confined almost exclusively to the iron, thus giving a magnetic circuit of definite and easily computed length and cross-section.

There is some leakage of magnetic flux from the iron into the air. For dynamos of ordinary sizes and shapes it varies from 15% to 30% of the flux through the field coils. It may be separately calculated and allowed for.

The **magnetizing force**, represented by the symbol $\mathcal{H}$, may be defined as the rate at which the magnetic potential diminishes in a magnetic circuit. The total fall of magnetic potential in a magnetic circuit is equal to the M. M. F., just as the total fall or drop of electric potential in an electric circuit is equal to the E. M. F. The total difference of magnetic potential in the magnetic circuit shown in Fig. 14 is 628.32 gilberts. As this circuit is symmetrical and uniform throughout, the drop of magnetic potential is uniform and equal for each unit of length. The mean length of the circuit being 45 cms., the rate of fall of potential is about 14 gilberts per centimeter all around the circuit. This is the magnetizing force, or the magnetic force, represented by $\mathcal{H}$. When there is no iron or other magnetic substance in the circuit, the value of the magnetizing force $\mathcal{H}$ is equal to the flux density $\mathcal{B}$.

If in any magnetic circuit the M. M. F. expressed in gilberts is divided by the length of the magnetic circuit in cms., the average value of the magnetizing force will be obtained. Thus in a long helix, if there is a M. M. F. of 500 gilberts, and the magnetic circuit inside the helix has a length of 50 cms., the magnetizing force will be 10 gilberts per centimeter, and the flux density will be 10 gausses, provided there is no magnetic substance in the circuit.

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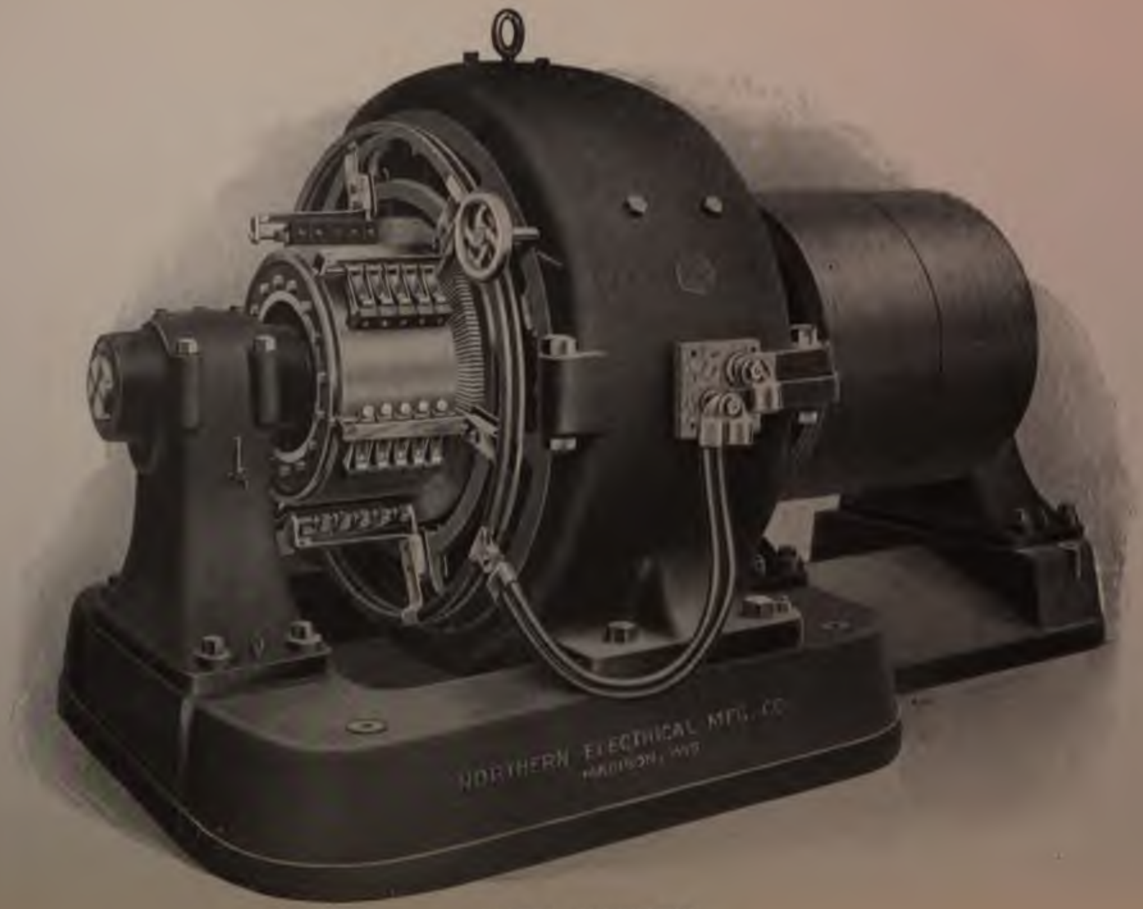

BELTED GENERATOR.
Ring Type, Three Bearing, Six Pole.

If there is iron or any other magnetic substance in the circuit the magnetizing force will still remain 10 gilberts per centimeter although the magnetic flux density will be greatly increased according to the permeability of the magnetic circuit.

FORMS OF FIELD MAGNETS.

The function of the field of a dynamo is to provide a space filled with lines of magnetic induction which the conductors of the armature may cut, thus causing an electromotive force to be generated in them. It is immaterial to the generation of an electromotive force whether the armature or the field revolves, though generally the field is stationary. It is usually desirable to maintain the magnetic induction or number of magnetic lines at constant value. The first field magnets to be used were permanent steel magnets, and small dynamos are still built with them. The magneto-machine is a shuttle-wound dynamo having its field produced by permanent magnets. Such machines can not, of course, have as large a capacity as others equipped with electromagnets, and they are subject to loss of magnetism which after a while is liable to render them useless unless they are remagnetized. The fields of modern dynamos are supplied by electromagnets, connected to the circuit of the dynamo according to the purpose for which it is built. The different forms, named according to the winding are, — the magneto, the separately excited machine, the series machine, the shunt machine and the compound-wound machine.

The separately excited dynamo has its field coils fed from some outside circuit. This form of winding is not used much with direct current machines except for special cases. Its place is with alternate current machines where it is inconvenient to excite a machine by its own current.

Field magnets for dynamos and motors have been made in almost every conceivable shape. Electrically speaking the best form to use is one which has the most compact arrangement, presenting the shortest path for the flow of magnetism, the greatest cross section, and the fewest number of joints. Such a form would have the greatest permeability and would consequently be the most efficient. But the form which is most desirable electric-

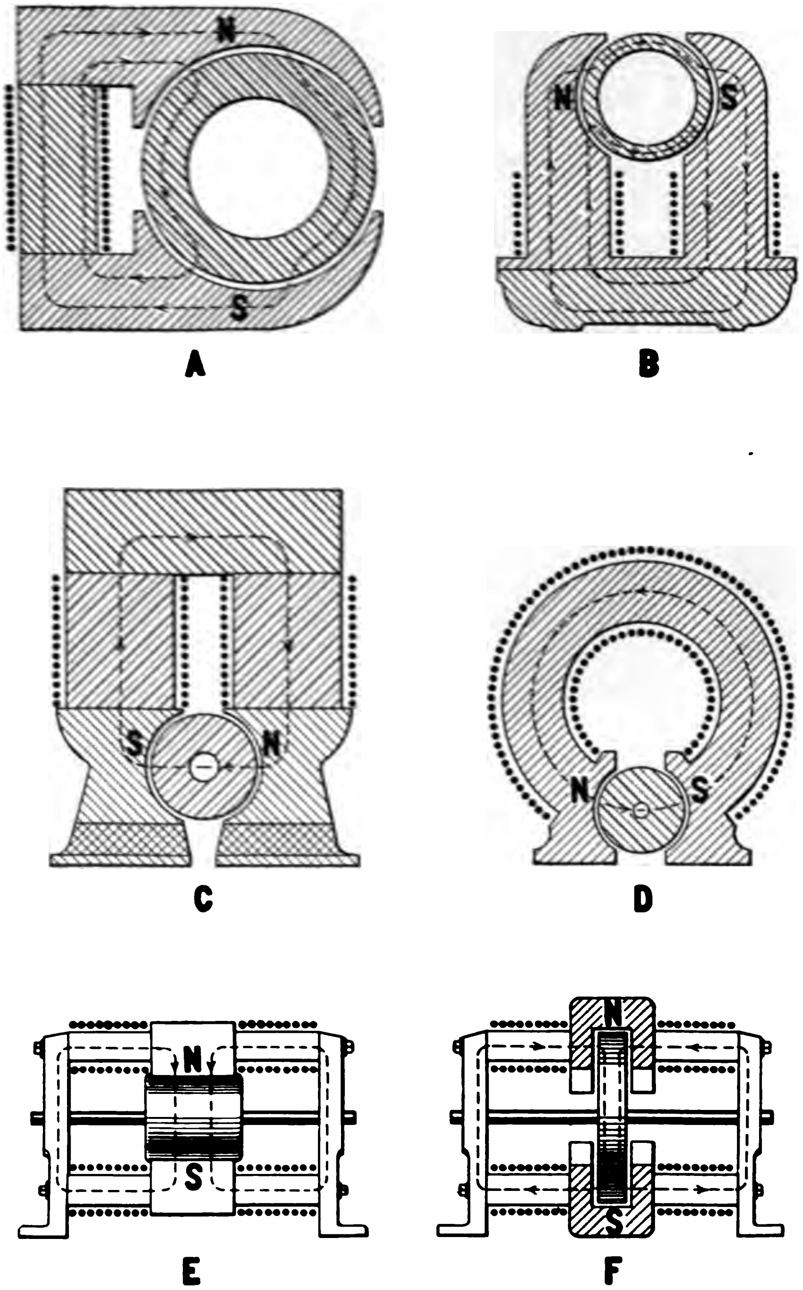

Fig. 15.

ally may often be very difficult and expensive to construct so that the forms which have become fixed in practice are usually the ones which have been found to give the best results at lowest cost.

Some of the more usual forms are shown in Figs. 15, 16 and 17. All types come under three principal heads; the single, the double, and the multiple magnetic circuit.

The horseshoe form is the type of the single circuit bipolar field magnet frame. It is placed upright, C Fig. 15, or inverted, B Fig. 15. The Edison machine is a type of the upright form, which has the disadvantage that it must be mounted on a zinc, brass or some other non-magnetic base, because if the latter were of cast iron, or any good magnetic conductor, the magnetism would be largely diverted by it instead of passing through the armature. The Thomson-Houston machines, now built by the General Electric Co., are of the inverted horseshoe type. The Jenney Electric Co. uses the horizontal type and the vertical form is employed by the Excelsior Electric Co. A modification of the horseshoe magnet type as generally used, is that employed by the Eddy Electric Co., D Fig. 15. In this machine there is no yoke and simply a half ring joins the pole pieces. This gives a very good magnetic circuit but is expensive to build. Another modification is the one magnet form, which has only a single coil wound on the portion of the frame corresponding to the yoke, as A Fig. 15, and this, like its prototype the double coil frame, is made in several positions.

The double magnetic circuit form is equivalent to two horseshoe magnets joined at the poles. The chief advantage of this type is in its greater mechanical strength. The coils are sometimes placed on the two upright sides which connect the top and bottom yokes, as shown by K. Fig 16 and P Fig. 17, the pole pieces being formed on the yokes. Again the pole pieces are elongated to make room for the coils and are placed either vertically or horizontally as shown by G and I. The double magnetic circuit type with internal poles (G Fig. 16) is called *ironclad* and is used in places where the machine might be exposed to accident. A modification of this type is used for street railway motors, the outside connecting pieces are thinned out and spread around the motor so as to completely cover it, affording perfect protection against injury from water or from mechanical means.

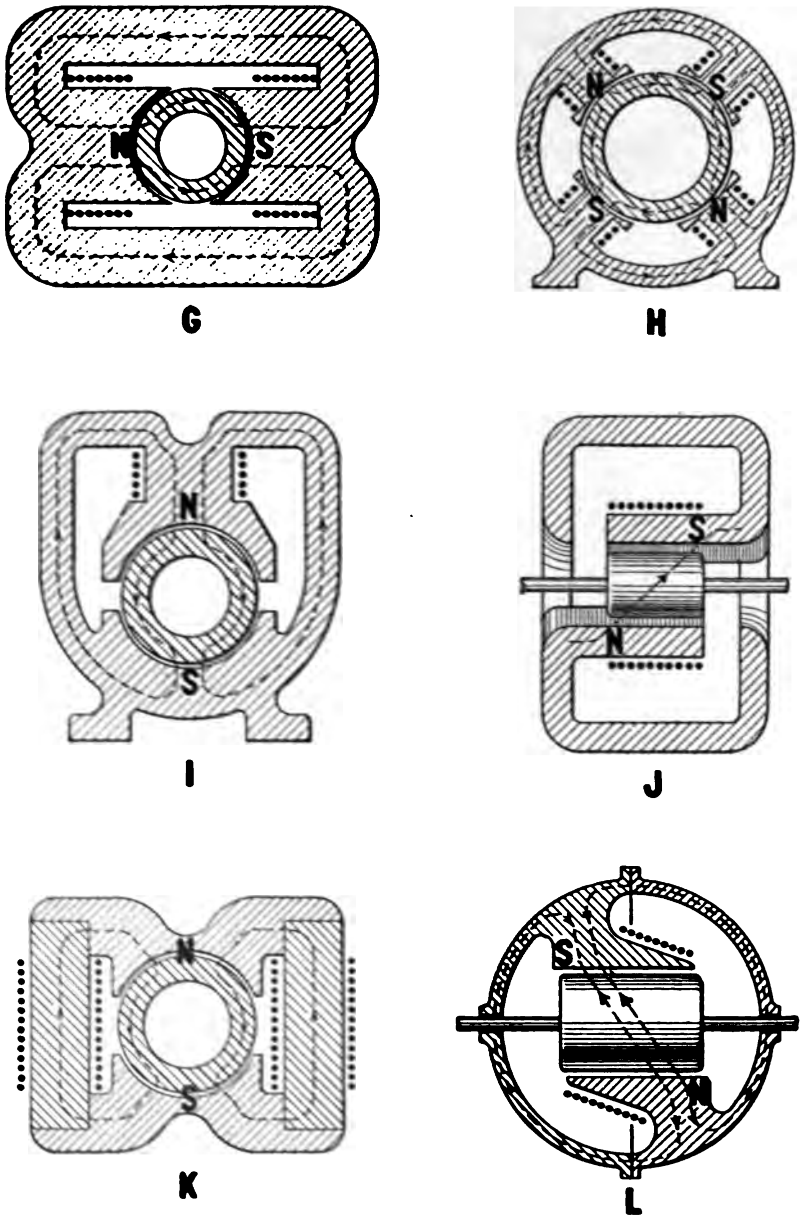

Fig. 16.

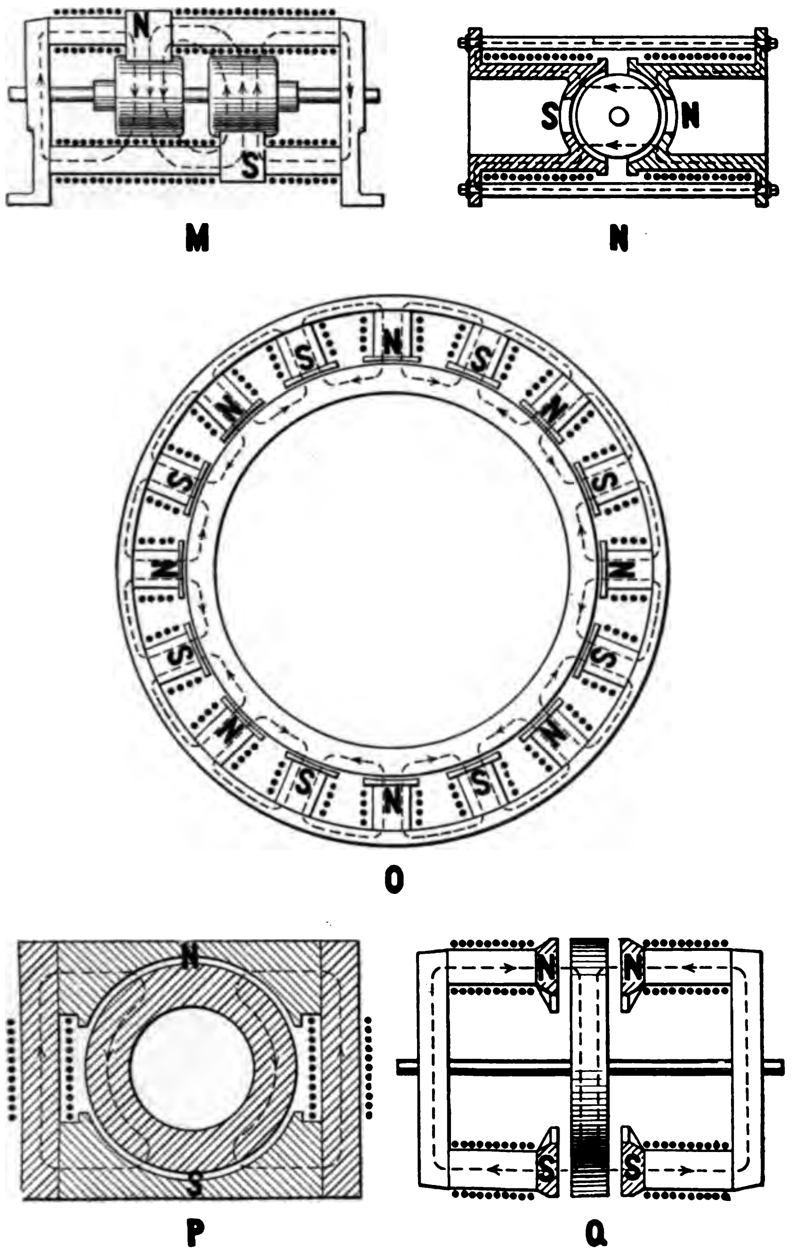

Fig. 17.

A curious modification is the Thomson-Houston "bird cage" arc light machine shown by N Fig. 17. It has tubular magnets and the pole pieces are formed to receive a spherical armature. The return circuit or yoke is made of wrought iron bars. The advantage claimed for this construction is that less wire is needed. Another ingenious form of the ironclad type is that used in the Lundell motor shown in section by L Fig. 16. There is but one coil which encloses the pole pieces, the whole being in turn completely incased by the remainder of the magnetic circuit.

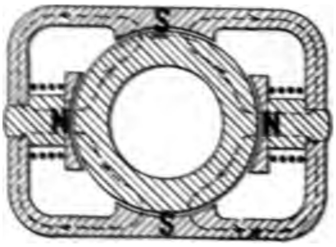

Fig. 18.

The double magnetic circuit type, modified by the formation of a pair of extra poles on the pieces which form the return circuit as in Fig. 18, gives rise to the four-pole type and hence to the multipolar multi-circuit type.

The multipolar field magnets are usually circular in form with inwardly projecting pole pieces. Siemens & Halske use a form having outwardly projecting pole pieces with the armature ring rotating outside the field as shown in Fig. 20. This gives a better magnetic circuit but introduces mechanical difficulties in securing armature supports. Sometimes the multipolar field is built with the coils on the yokes between poles instead of on them.

The circuit of the Ball dynamo is shown by M Fig. 17, and that of the Brush dynamo by Q. Fig. 19 and H Fig. 16 show magnetic circuits of typical small multipolar dynamos. The magnetic circuit of a large multipolar dynamo with inwardly projecting poles is shown by O, Fig. 17.

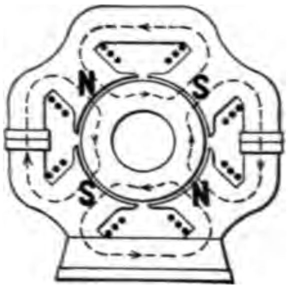

Fig. 19.

For large machines the multipolar type is most in use because it results in a saving of both copper and iron and gives a more symmetrical arrangement. Below 10 K. W. capacity the bipolar forms are to be preferred as they are simpler. The bipolar single circuit types are generally superior to the double circuit types because they need less wire and are less subject to magnetic leakage.

DYNAMO CONSTRUCTION.

The Armature. The armature of a dynamo is that portion of the machine in which the electrical output is generated. The principle underlying every armature is the law of induction, that any conductor which cuts across a magnetic field has electromotive force generated in it which tends to set up a current. The various armatures of modern commercial machines are the mechanical means which experience has shown to be best adapted to carrying out the law of induction serviceably and efficiently under the various conditions and uses to which the machines are subjected.

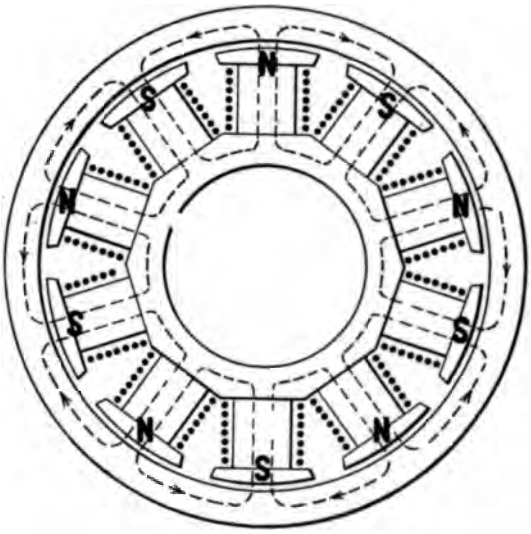

Fig. 20.

The two forms of armature in common use and from which nearly all others have been derived are the Gramme or *ring-wound* armature, and the *drum* or shuttle-wound armature. Fig. 21 shows a diagram of a simple ring armature with one coil, and Fig. 22 a diagram of a drum armature. In practice the number of coils on a single armature is of course large. In the Gramme type the iron core is a ring on which the coils are wound. In the drum type the core is a cylinder, the coils being wound on the surface and ends. Where slow speed is desired the ring armature is most generally used; the ventilation is better and a high insulation is more readily obtained.

There is also the pole armature, with its conductors wound upon iron cores projecting radially outwards; and the disk armature which has no core, the conductors forming a flat disk which rotates in a narrow gap between the pole pieces.

The Armature Core. The iron armature core not only serves as a support for the armature conductors but also serves as a medium of low reluctance through which the magnetic flux from pole to pole may readily pass.

If the core consisted of one solid piece of metal, it would, since it rotates in a varying magnetic field, have currents induced in it, as is the case in the conductors on its surface. The iron itself would form a closed circuit for these currents, which are known as Foucault or eddy currents. Their presence would not only be a waste of energy, but would also cause injurious heating. These currents are, however, largely reduced by laminating the core, that is, by building it up of thin insulated sheets of iron. These sheets or discs are perpendicular to the direction in which the induced currents would flow, and therefore break the otherwise closed circuit. The discs, being perpendicular to the direction of the induced currents are parallel with the lines of magnetic flux and therefore this lamination does not increase the resistance to the magnetic flux. The core of a drum armature is made up of a number of circular discs, and a ring core is made up of a number of similar rings. The discs may be insulated from each other by sheets of paper, a coating of varnish or by rust that is allowed to form on their surface.

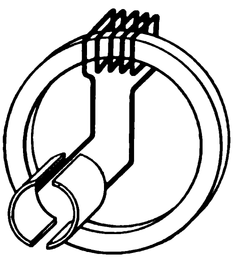

Fig. 21.

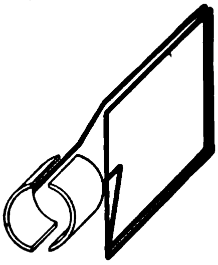

Fig. 22.

The higher the permeability of the material of which the core is composed, the less will be the hysteresis loss and the greater may be the magnetic flux per unit of cross section; the core discs are therefore punched out of the softest sheet iron or soft steel, which in some cases is afterwards annealed.

It has largely become the practice to use **toothed** armature cores shown in Fig 23, the conductors being laid between the teeth and within the outside surface of the core. The air-gap between the core and pole pieces can then be reduced to a minimum, and the conductors are well protected from injury. The conductors are also securely held in place. Such cores are, however, more expensive to make and unless proper precautions are taken, the teeth are likely to set up eddy currents in the pole piece surfaces.

Armature cores are usually built up on an internal frame or skeleton which is in turn firmly keyed to the shaft. In drum armatures the core discs may be keyed directly to the shaft, or the shaft and hole through the discs may be made square or octagonal. The discs are sometimes held together by large nuts screwed directly on the shaft, or, as is usually the case, by bolts passing through the discs. In the latter case end-plates somewhat thicker than the discs are provided, and to reduce the presence of eddy currents which would occur if the plates were of iron, they are sometimes made of brass or other non-magnetic metal. These bolts and end-plates are always insulated from the core by tubes and washers of paper, fiber, or mica.

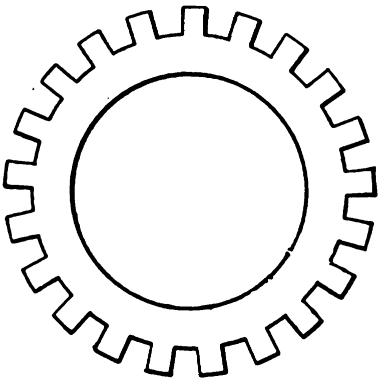

Fig. 23. Toothed Armature Core.

The core of ring and of large drum armatures, being in the form of a ring, must be supported on some form of spider. This consists of a hub or sleeve keyed to the shaft and is provided with projecting arms which support the core. A simple construction is shown in Fig. 24. Two spiders are used, the core being clamped between them. It will be noticed that the bolts do not pass through the core and therefore are not in the path of the magnetic lines.

Before the conductors are applied the core should have all sharp or rough edges removed. In order to secure good insulation from the conductors the cores are covered with a few layers of

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insulating material; smooth cores have a continuous layer of insulation over their surfaces, whereas in toothed cores the insulation is applied only in the slots between the teeth.

Armatures of bipolar dynamos usually run at a speed of from 800 to 1,400 revolutions per minute; the armatures of direct connected machines and others which are of the multipolar type sometimes run as slow as 150 per minute, but their diameters may be so large that the peripheral speed is not far from that of a smaller machine. Under these conditions the centrifugal force acting on the conductors is quite appreciable.

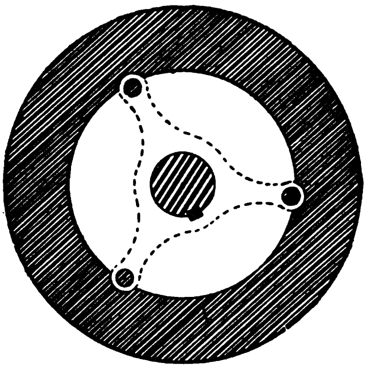


Fig. 24. Shaft and Spider Supporting Armature Core.

There is also another mechanical force to be provided for due to the magnetic pull exerted on the conductors by the field. It is against this pull that the steam engine driving the dynamo does work, and were they not strongly secured the conductors would be stripped from the armature. In order to prevent any motion of the conductors during the operation of an armature, hard brass wire is wrapped around the outside in bands; these are called **binding wires.**

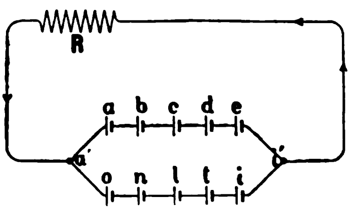


Fig 25.

On account of the high speed and small clearance in the air-gap, armatures are very carefully *balanced* to prevent injurious vibration. The usual method of doing this is to support the armature and its shaft on two horizontal, wedge-shaped metal rails called knife edges. The armature is then given a turn and it is noted whether there is any tendency to come to rest with any particular part of the armature downwards. If this is the case, small pieces of lead are inserted on the opposite side until the armature will come to rest in any position.

Armature Windings. The law of induction tells us that a loop of wire carried through a field in such a manner as to vary continuously the number of lines of force that are included within its boundary will have an E. M. F generated in it. Two loops connected in series will double the effect, or twice the field strength will also double the effect. Dynamos are designed with this in view, and to produce the desired voltage the coils are made of a certain number of turns and the fields of a certain strength.

There are two general methods of winding armatures giving rise to the terms **closed coil** and **open coil.**

Closed Coil Armatures. The closed coil type of armature is used for constant potential machines, in incandescent lighting and power distribution, and in some cases for constant current machines. The coils are wound continuously around the ring or cylinder as the case may be, the end of one coil being joined to the beginning of the next, and this junction is connected with a segment of the commutator.

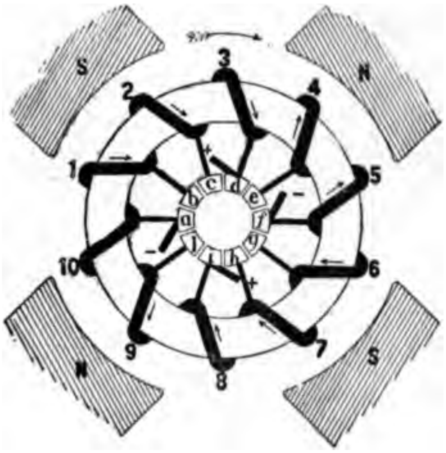


Fig. 26.

Each coil adds its quota to the electromotive force at the brushes, the amount depending at any moment on the position of the coil in the field. As the coils revolve the E. M. F. generated by some coils is increasing, while that generated by others is decreasing; but the sum total between the brushes remains the same, for the loss in effectiveness of one coil is balanced by the gain in another. The effect of the coils in a closed circuit winding is sometimes compared to a set of voltaic cells, one in each coil, as shown in Fig. 25. This would, however, be a more accurate illustration if the voltage of the cells were of varying strength according to their position in the chain. When two brushes are used there are two paths for the current from one brush to the other through the armature, and the resistance of the armature is then $\frac{1}{4}$ the resistance of the total amount of wire upon it, for the total length of wire is halved and the halves are connected in parallel.

There have been many variations in winding, all based on the drum or ring winding, and resulting from the necessity of reducing the cost of manufacture and from the increase in the number of poles used in a single machine. The armatures of small machines are usually wound with copper wire, which in larger machines is replaced by copper bars, these bars being laminated above certain sizes to prevent the occurrence of eddy currents in their own mass.

The use of more than two poles greatly increases the variation which it is possible to make in the windings. Fig. 26 illustrates the winding and connections of a four-pole ring armature. As there are four neutral points it is necessary to use four brushes, two positive and two negative, the winding forming a closed circuit from brush to brush. To supply the external circuit the two positive brushes are connected giving one positive terminal, and the two negative brushes are connected giving one negative terminal. Thus the external current in passing through the machine subdivides at the two brushes and again subdivides in the armature, therefore only $\frac{1}{4}$ of the total current passes through each conductor. The internal resistance is $\frac{1}{16}$ of that of all the wire on the armature. Similarly more poles would cause the current to divide a greater number of times.

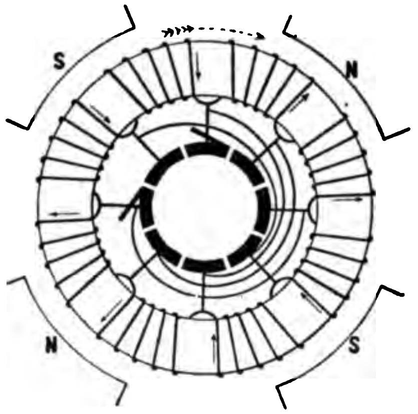


Fig. 27. Four-Pole Ring Winding.

It is not always necessary to have as many brushes as there are neutral points or poles, although this is usually the case. By the simple device of **cross-connecting,** a diagram of which is shown in Fig. 27, the number of brushes may be reduced to two. Each coil is cross-connected with others occupying a similar position under the corresponding pole. This cross-connection may be either in the armature itself or in the commutator.

A method by which armature windings and connections are clearly shown consists in laying the poles and winding out in a plane surface, or in showing the winding as it will appear when unfolded upon a plane surface. Such a development of the winding of a ring armature is shown in Fig. 28. Figs. 29 and 30 show two windings called the **lap** and the **wave winding** respectively. They are more like the drum winding than the ring, being entirely exterior to the core. A portion called an *element* is shown heavier than the remainder of the windings which are all similar to it.

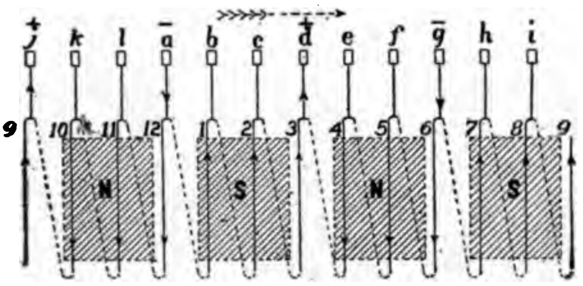


Fig. 28. Developed Ring Winding.

A conductor on a revolving armature generates an E. M. F. under a north pole in the opposite direction to one under a south pole, so that it is possible to lay out a wire on the surface of an armature, carrying it across the ends from point to point, in such a way that it will be subjected to an inductive effect tending to

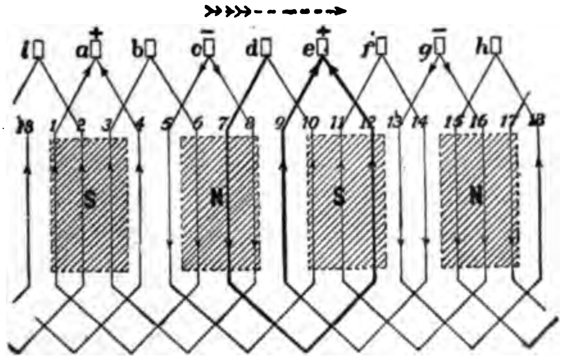


Fig. 29. Developed Lap Winding.

drive the current in the same direction throughout its length. The two ways of obtaining this result are illustrated in Figs. 29 and 30. The reason for calling them *lap* and *wave* windings is that one doubles back on itself every turn, while the other goes ahead in a continuous zig-zag, as will become apparent by following an element.

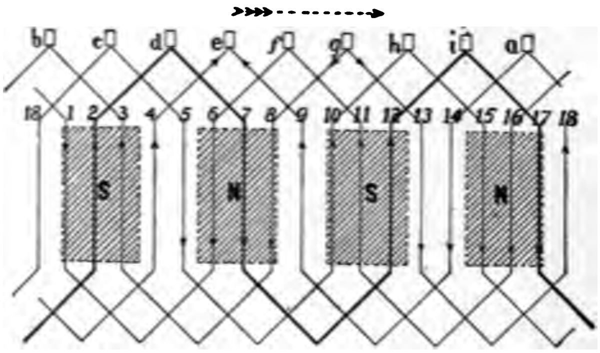


Fig. 30. Developed Wave Winding.

Open Coil Armatures. In the open coil type of armature, which is used chiefly for arc lighting or constant current machines, the various coils, which are few in number, are not interconnected; each winding performs its function independently of the others, and is cut into the circuit by the commutator at the time of greatest activity and is entirely disconnected from the circuit when it is idle.

The commutators of such machines are made up of few segments which are insulated from each other by air spaces. These machines generally spark considerably at the brushes on account of the actual break in the circuit of the separate armature coils.

Fig. 31 shows a diagram of a Brush arc machine which is ring-wound. There are four coils, the two coils *A* and *C* of one winding being in series and terminating in a two part commutator, while the others *B* and *D*, also in series, terminate in another two part commutator. The commutators are placed side by side and the segments are made long enough to overlap so that sometimes the brushes are connected to one pair of terminals, sometimes to the other, and sometimes to both at once. When the brushes *E E* touch both sets of terminals at once thus bringing the two windings in parallel, a current would be set up in one winding by the other owing to the difference in activity of the two, were it not for the high self-induction of the coils. The contact between the brushes and a pair of terminals breaks just when the coils connected have reached the point of least activity. The completed dynamo has another set of coils between those shown, on the same ring, and another commutator and pair of brushes beside the first set. One brush of the first set is connected to the outside circuit, the other is connected to one of the brushes of the second set while the remaining brush is connected to the other terminal of the outside circuit through the field coils. In this way the two sets of windings are brought in series with each other and owing to their relative positions, one is at a maximum activity when the other is at a minimum, one increases as the other decreases, and *vice versa*, so that the sum total of the action tends to keep the current from fluctuating.

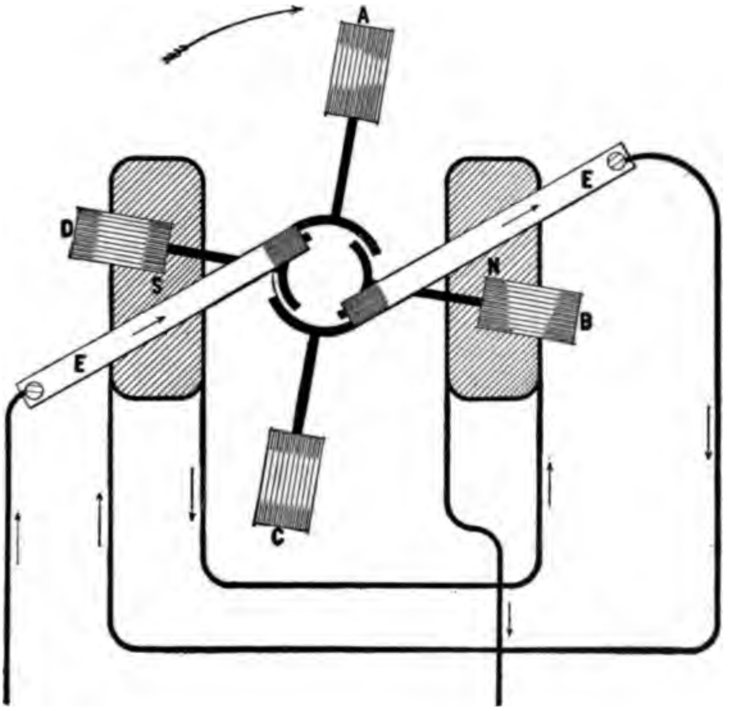


Fig. 31. Diagram of Brush Arc Dynamo.

Commutators. It has been shown how current generated in a coil revolving in a magnetic field is necessarily alternating, being generated in one direction through the coil when the coil is rising through the field and in the opposite direction when it is descending. The first machines built were alternating current machines, but as the alternating current could then only be used for a few purposes the invention of the commutator soon followed. The simplest form of dynamo is a single coil revolving in a field, the terminals of the coil ending in two pieces of metal which form the halves of a circle, and with which the brushes are in contact. As the coil rotates, first one terminal and then the other comes under a brush. If the brushes are put in the right place the terminals will always have the same polarity when they make contact with the brushes so that a continuous current can be drawn from them. The current is continuous however, only as regards direction for the strength of the current is varying.

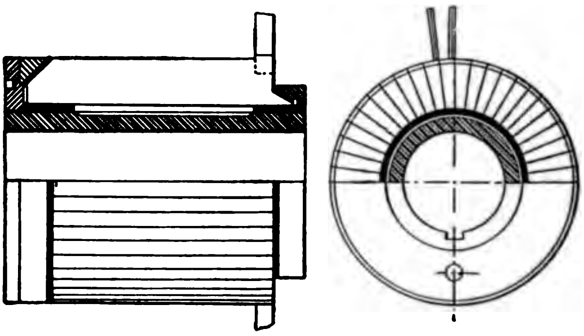
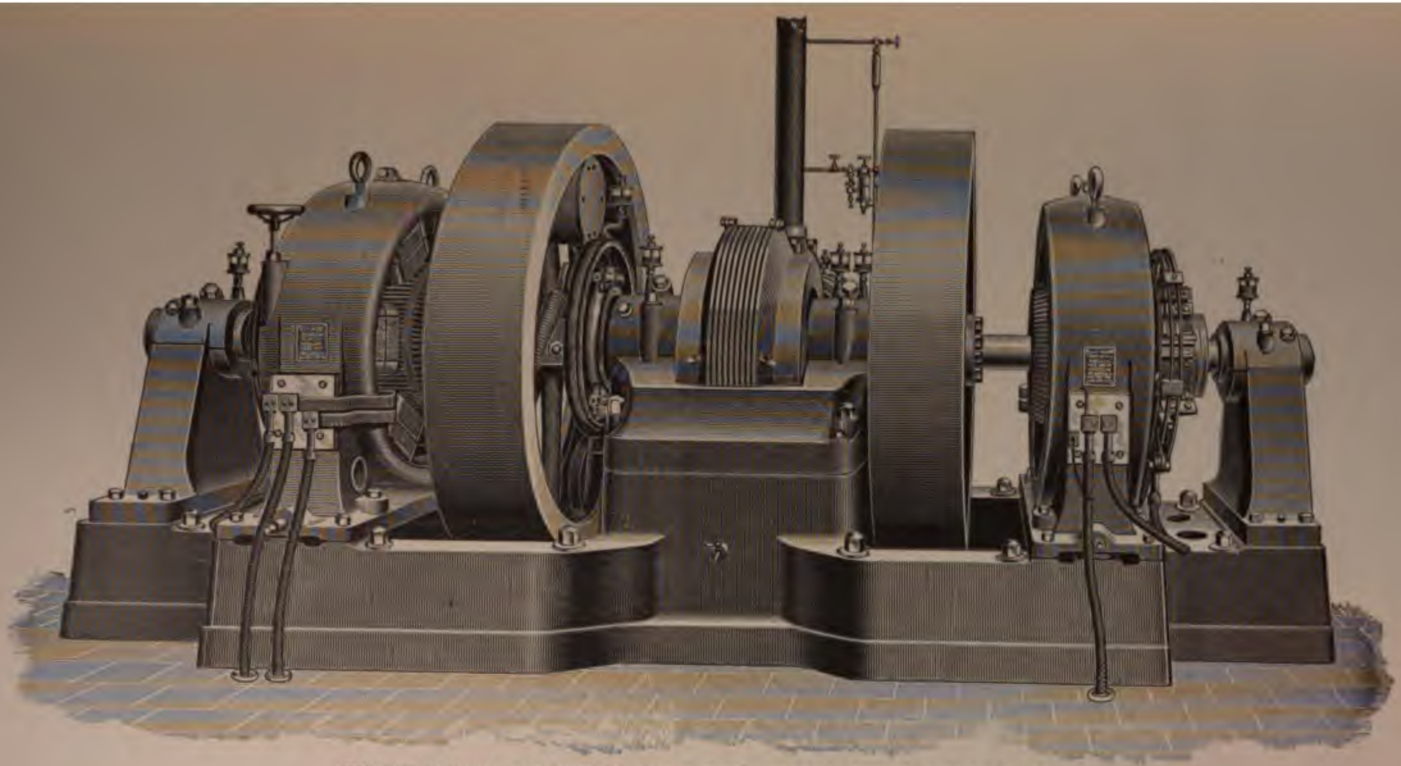


Fig. 32. Commutator.

As the coil moves into the denser part of the field the current increases, and as the coil moves out the current decreases. If we had two coils at right angles to each other, moving through the field in the same time, the pulsation would only be half as great as with one. We can therefore make the pulsation as small as we like by increasing the number of coils and hence the number of commutator segments. The fluctuations become perceptible in a two pole machine when less than 30 coils are used and the commutator bars seldom exceed 100 for this type of machine on account of increased expense. In larger machines the



ENGINE DIRECT-CONNECTED WITH TWO WESTINGHOUSE GENERATORS.

Ames Iron Works.

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total number of commutator segments increases with the number of pairs of poles.

The commutator must be well designed mechanically as well as electrically. Each segment must be carefully insulated from adjacent ones and from the shaft upon which it is built up. The insulation between the segments consists of sheets of mica which have been selected for firmness, freedom from cracks, and uniformity in thickness. The segments taper toward the center so that they will build up into a cylinder. The whole is firmly clamped together by insulating rings held in place by metal rings and lock nuts. Figs. 32 and 33 show two different methods of securing the assembled commutator bars. The best material for the commutator bars is hard copper or silicon bronze which should be as nearly pure as possible and uniform in its structure. The commutator is designed larger than necessary so as to allow for the continual wearing away of its surface; and also to allow it to be turned down from time to time when the surface becomes rough as the result of uneven wear or accident.

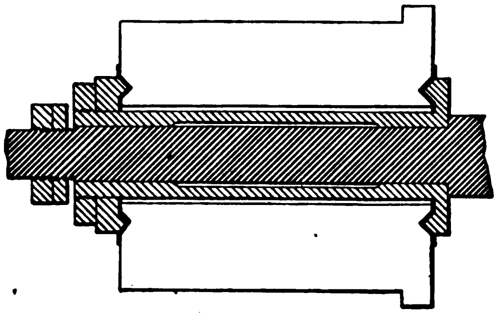

Fig. 33. Commutator.

Brushes. The cross section of the brush must always be large enough to carry the maximum current which it is likely to be called upon to furnish, with a liberal factor of safety. The thickness at the contact with the commutator should not be less than one and a half times the insulation between the bars and is usually greater. The material must be softer than that of the commutator so as to wear the brush rather than the commutator.

There is a large number of different forms of brushes, each having its special advantages and disadvantages. In the Brush arc dynamo the brush consists of a simple strip of sheet copper having slits in it to insure good contact, and is set almost tangent to the commutator.

The wire brush has been much used and is still employed; it consists of a bundle of fine copper wires all soldered together at the end furthest from the commutator, and being inclined to its surface, the brush has the contact end beveled to fit the commutator in order that the ends of all the wires may make contact.

Copper gauze brushes consist of sheets of fine copper gauze folded or rolled up and pressed into rectangular form. These brushes owing to their soft spongy nature secure excellent contact with the commutator.

The carbon brush is now used more than any other. It is usually applied radially giving the advantage that if the machine is run backwards, through accident or intention, there is no danger of ruining the brush by causing it to trip on the edge of some commutator bar that might be slightly out of place. It also wears a better surface on the commutator and the amount of wear is much reduced. The collection of carbon dust is far less objectionable about a commutator than that of copper dust being less likely to cause a short circuit. The main advantage of the carbon brush is the reduction of sparking. As carbon has a high specific resistance it tends to keep the current down when the commutator bars are short circuited by coming under the brush, and there is therefore little or no sparking when a bar breaks contact with the brush. This advantage becomes less marked in machines having many segments in the commutator and very low difference of potential between them, for in such machines there would be little sparking even with copper brushes having high conductivity.

Brush-Holders. The brush must be held rigidly in position by a mechanism called the **brush-holder** which is capable of being revolved part way around the shaft so as to shift the point of contact between the brush and the commutator. The holder is usually mounted on a collar which in turn is mounted on a hub formed by a projection from the journal box. An insulated handle is provided by which to shift the brushes to the desired position, and it is often made to screw into the collar in such a way that the brush-holder can be locked in any position. In very

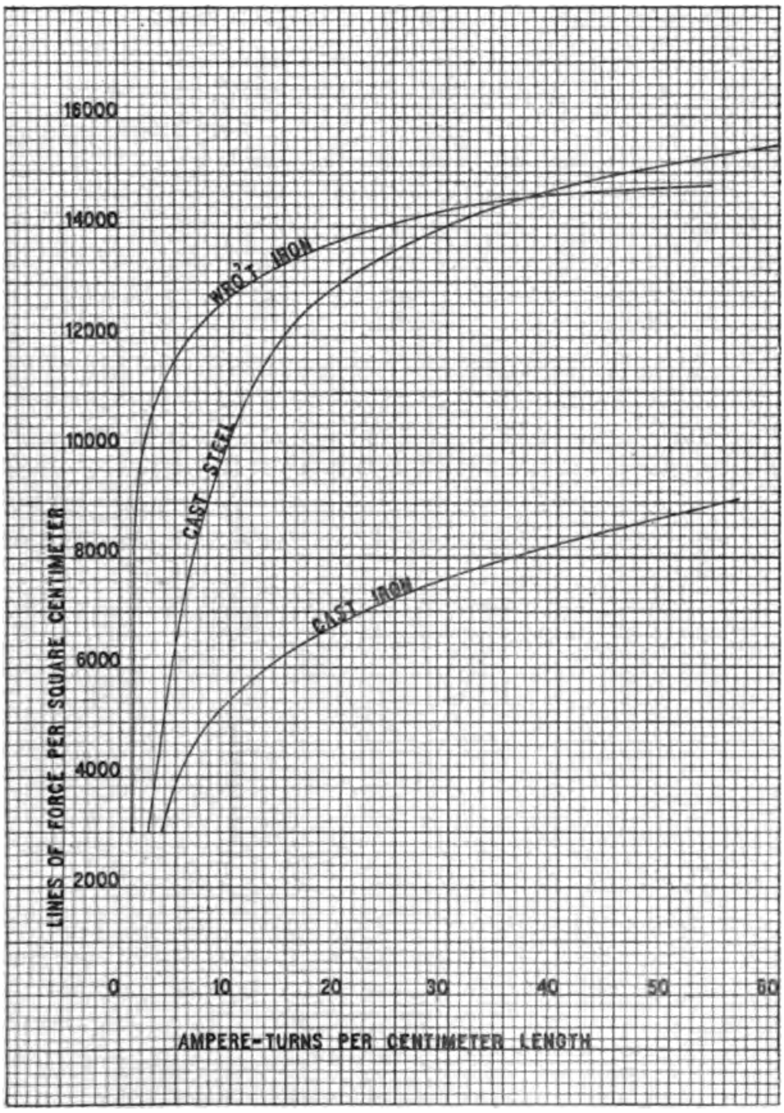

Fig. 34. Curves of Magnetic Induction.

large multipolar machines where there are as many brushes as poles, a substantial ring is formed separate from the machine. This ring is supported from the field casting by arms, and is shifted by the aid of a hand wheel and worm meshing with teeth on the ring.

Except in very small machines brushes are subdivided into two or more parts pivoted on the same shaft of the brush-holder. By this means of construction one brush at a time may be lifted and examined without breaking the circuit or interfering with the operation of the machine. The brush-holders are generally provided with adjustable springs which give the brushes a proper pressure on the commutator. If much of the current is allowed to pass through the springs, they are heated and soon lose their temper, and they cannot then exert sufficient pressure on the brush. The springs are therefore insulated, or arranged so that only a very small part of the current passes through them.

Field Magnets. In the construction of the field magnets the principal materials used are cast iron, cast steel, and wrought iron. Usually a combination of two of these is used. In Fig. 34 are shown curves of magnetic induction for cast iron, wrought iron and cast steel.

Cast iron has the lowest permeability of the three and hence for a certain magnetic flux must necessarily have a larger cross section. It is customary to allow a density of about 45,000 lines per square inch for cast iron. This material is used, on account of its cheapness, for yokes, polepieces, bases, or in general where extra weight or size is not objectionable. This extra weight is often an advantage since it gives greater firmness and stability.

Wrought iron is generally considered to have the highest permeability of any material and a density of about 90,000 lines per square inch is usually allowed. Owing to its high permeability, wrought iron is used where a small cross section is desirable, and this is especially the case in field cores. To wind a certain number of turns upon a wrought-iron core will require a considerable less length of wire than if a core of some other material large enough to carry the same magnetic flux were used. If a cast-iron core were used the length of wire would be about 1.5 times that needed for a wrought-iron core for a given number of turns.

The improved and cheaper processes of casting soft steel having a low percentage of carbon, has led to its adoption for field magnets in many dynamos. Cast steel has a very high permeability and some varieties have a higher permeability than that of wrought iron; it is customary however to allow a density of about 80,000 or 85,000 lines per square inch. Cast steel is always used for field magnets where lightness and small size are desirable.

Field Coils. For convenience in construction and repair of field coils they are usually wound on a separate form and then placed in position on the cores. The cylindrical form upon which they are wound often consists of tubes of brass or tin, having flanged ends. The coil should be insulated from this tube by a few layers of thick paper or fibre. The finished winding should be perfectly symmetrical or as nearly so as possible. The leads from the coil should be carefully protected and insulated; this is especially the case with the inner terminal, which is usually carried out through a hole in one end of the tube or spool.

As the conductors of series coils often must be of large size, they are difficult to wind, and therefore usually consist of several smaller wires connected in parallel, or of ribbons or strips of sheet copper. In compound-wound machines the series and shunt windings may be separate or on the same spool. In the latter case the shunt coil and series coils are wound in separate compartments of the spool. When the coils are separate there is the advantage of greater ease in repair and also greater radiating surface.

SPARKING.

It sometimes happens that heavy sparking takes place at the brushes of a dynamo and if this is not prevented it soon burns and roughens the surface of the commutator and the brush so badly that the dynamo is thrown out of service. Sparking may result from either mechanical or electrical faults. If one bar of the commutator is higher or lower than the rest there will be a spark every time it passes under the brush, or if the lead from an armature coil to one of the commutator bars should become disconnected, or if there should be a break in some other part of the coil, there will be flashing when the bar passes under a brush. If the sparking is continuous and not due to mechanical causes the brushes should be rocked one way or the other until a position is found where the machine runs sparklessly, or nearly so.

When a dynamo is in operation the current passes from the positive brushes through the external circuit to the negative brushes, and then sub-divides and passes through the armature to the positive brushes. To understand the production of sparking due to an incorrect position of the brushes it is necessary to consider the commutation at one brush only.

Referring to Fig. 35, it is evident that the current passes through coils 2 and 3 to segment *d* in one direction and through coils 5 and 4 to segment *d* in the opposite direction. From segment *d* the current passes to the positive brush and to the external circuit. Further movement of the armature in the direction of rotation will bring both segments *c* and *d* under the positive brush at the same time and coil 3 will then be short circuited. That is, these two segments, the brush and coil 3 will form a complete circuit of very low resistance, and the current may pass from coil 2 directly to segment *c* and the brush, and from coil 4 directly to segment *d* and the brush. As the armature continues to rotate, coil 3 will come under the north pole and segment *c* under the positive brush. The current must then pass from coil 4 through coil 3 to segment *c* and the brush. In passing the brush coil 3 is therefore at first short circuited and afterwards is traversed by a current in the reverse direction to that originally considered. Each coil successively passes through the same positions. Now, suppose the position of the positive brush is such that when coil 3 is short circuited it is cutting no lines of force and therefore generating no E. M. F. Then there will be no current and as the coil passes to the right it will be perfectly idle, and when segment *d* leaves the brush the large current from coil 4 should pass through coil 3 to get to segment *c* and the brush. On account of

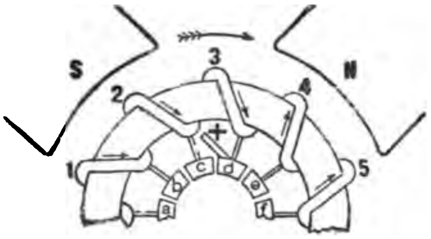

Fig. 35

the large self-induction of the coils, however, the current cannot immediately rise to its full value in coil 3 and hence will prefer to jump from segment *d* to *c*, causing sparking. Now consider the result when the brush is shifted to the left or backwards, so that when the coil is short circuited it is still cutting lines of force. The generation of a slight E. M. F. will cause a large current to flow on account of the very low resistance of the coil, and the direction of this current will be opposite to that which the coil must next convey. For such a position of the brush excessive sparking will result.

Now consider the brush to be moved forward or to the right, so that while the coil is short circuited it is passing into the field at the right or under the north pole. The E. M. F. generated by coil 3 will then cause a current to flow which will be in the same direction as that in coil 4, and when segment *d* passes from under the brush the current in 3 already has a certain value. The correct forward position of the brush is such that coil 3 generates just sufficient E. M. F. to produce a current equal to that which passes in coil 4. No sparking will occur under these conditions, as the effect of self-induction has been counteracted and the current from coil 4 will readily pass to 3. If the brush is too far forward, too large a current will be generated, and cause sparking. The brush must be set forward a greater amount for large armature currents, since the short-circuited coil must generate a higher E. M. F. to produce the large current. The distortion of the field by the armature also necessitates the shifting of the brushes forward.

INSTALLATION AND OPERATION.

A good foundation is the first requisite in a dynamo installation. With belted machines the high speed may give trouble if the foundation is insecure. With direct driven machines the engine and dynamo should be mounted on the same bed plate if the size permits. In selecting a position for the dynamo, freedom from dampness and dust should be secured and also good ventilation. A belted dynamo should be far enough away from its driving pulley to allow the belt to have good contact. A modern direct connected unit of 15 K. W. capacity is shown in Fig. 36.

Most machines of modern design are furnished with self-aligning and self-oiling bearings. If there are a number of machines in one installation each of which is fitted with oil cups, it may be advisable to have a system of oil pipes arranged to discharge oil through a stop cock into the oil cups. All oil cans should be of non-magnetic material, to prevent accidents which might arise from the attraction that would be exercised on an iron can when placed near some parts of the dynamo.

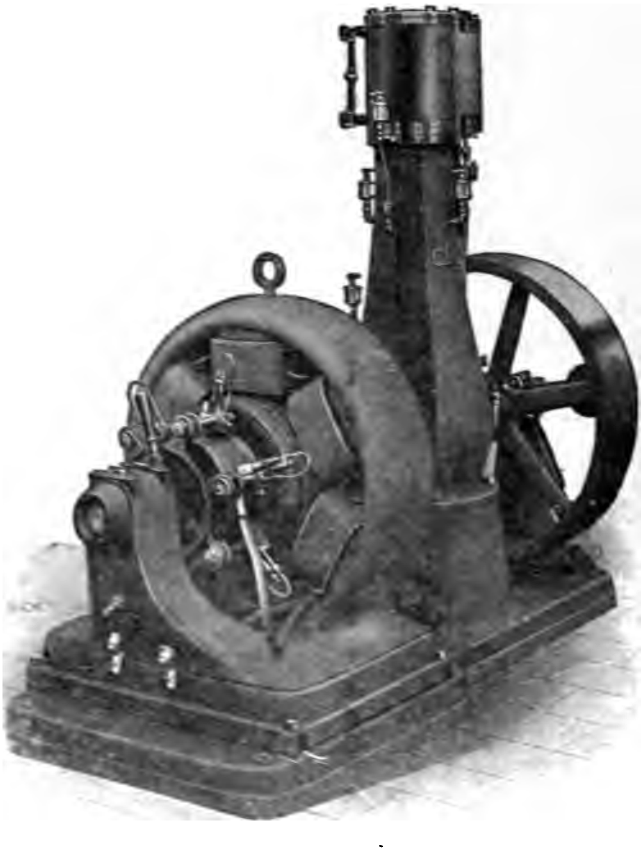

Fig. 36. Fort Wayne Direct-Connected Generating Set.

All electrical machinery should be kept scrupulously clean.

Brushes should at all times be kept in good contact with the commutator, with their faces properly bevelled, and if they are of metal, the armature should never be allowed to run backwards. The commutator must be kept smooth and polished, as any roughness will cause sparking and a burning of the surface. If each brush-holder supports two or more brushes as is generally the case, they should be staggered enough to prevent uneven wearing of the commutator. The commutator is the most delicate part of a dynamo and consequently requires special care. Commutators should be kept free from oil, as it will carbonize and cause flashing and may even partially short circuit the bars. Where carbon brushes are used the carbon dust should be wiped off from time to time. Some lubricant is generally necessary for the commutator, and it may be applied by holding against it a coarse cloth folded smoothly and containing the lubricant. Vaseline is generally used.

The position of the brushes should be such that the machine runs sparklessly and when a change of load causes sparking the brushes should be shifted at once to the right position, as the commutator will become so badly roughened if allowed to run long in this condition, that it will have to be turned down with a cutting tool. The term *sparkless* means that there are no sparks present sufficiently large to burn the metal. When a machine is running it is possible by looking tangentially to the commutator at the brush to see a line of these blue sparks under the brush.

Dynamos as a rule are not liable to many mishaps if they are properly built and if they receive proper care, but it is often difficult to locate certain faults. A new machine will sometimes refuse to generate when first started; this is often due to entire absence of residual magnetism, making it impossible for the machine to build up. This may be remedied by exciting the field from an outside source, either another machine or a battery. It is however more likely to be due to some bad connection, such as would be produced by getting varnish under a terminal washer or by a loose wire. Sometimes the terminals of the field coils are reversed so that they oppose each other, or perhaps the brushes do not make sufficiently good contact. A shunt machine will not build up if its terminals are short circuited.

Burn-outs in the armature are sometimes produced by excessive heating resulting from overload. A short circuit will very often throw the belt or stop the engine so quickly that there is not time for the armature conductors to melt. Continued overloads not great enough to throw the belt may char the insulation until two conductors lying side by side and differing from each other in potential, come into contact. Vibration due to a badly balanced armature or to an insecure foundation may produce the same trouble by causing abrasion of the insulation on the conductors, so that they touch each other or are both touching the iron core. Dirt between two adjacent commutator bars, due to the collection of copper and carbon dust, may short circuit the coil having terminals in these bars sufficiently to cause it to burn out. Sometimes the connecting pieces between the armature coils and the commutator segments become broken which unbalances the armature electrically, and causes sparking at the dead commutator bar.

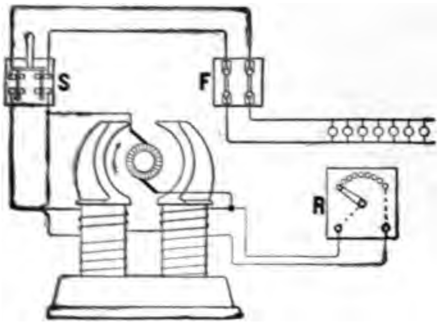

Fig. 37. Diagram of Connections of a Compound-Wound Dynamo.

The connection between a dynamo and its outside circuit should always be made through a double-pole switch which cuts both terminals from the circuit. A diagram of the necessary connections and wiring of a compound-wound dynamo is shown in Fig. 37. The leads from the external circuit are first connected to the fuses *F* in order to protect the dynamo from large or dangerous currents. If a current greater than a safe one for the dynamo passes through these fuses they melt and so break the circuit. From the fuses leads connect with the main switch *S*, and from this to the brushes through the series coils. The rheostat *R* is connected in series with the shunt coils for the purpose of regulating the field strength and hence the voltage of the machine. By moving the arm of the rheostat, more or less resistance is inserted or cut out from the circuit and therefore the current in the field coils is varied.

In most stations supplying electrical energy it is not desirable to have a single machine capable of taking the whole load of the station, for at low loads the efficiency would be small. It is therefore desirable to have several smaller machines, so that as the load of the station increases they can be successively added, and so always operated at full load when they are most efficient. The several machines are then connected in parallel between the bus bars from which the external circuits lead.

With shunt machines no trouble is experienced when several are running in parallel. Care must be taken before connecting a new machine to the circuit that it is built up to the same voltage as that carried on the bus bars, for if it is lower the higher voltage will send a current to the machine of lower voltage and drive it as a motor.

With series or compound machines the case is somewhat different. A conductor called an equalizer must connect together all the brushes from which the series coils start. Otherwise any tendency in one machine to raise its potential above that of the others would cause increased potential at the brushes and hence an increased current through the shunt coils, which would still further raise the potential; and if the potential became high enough it would reverse all the other machines on the circuit. This action is entirely obviated by the use of the equalizer, for if the potential of any machine should tend to rise it would drive some of its current across the equalizer connection and through the series coils of the other machines thus raising their potential with its own. Machines differing widely in size can be run together in this way if all are wound for the same potential.

TESTING.

When machinery has been installed it is customary to subject it to certain tests to determine whether or not it fulfills all the requirements. No test can be applied to determine the life of the machine. The life depends upon the general design, material of which it is made,

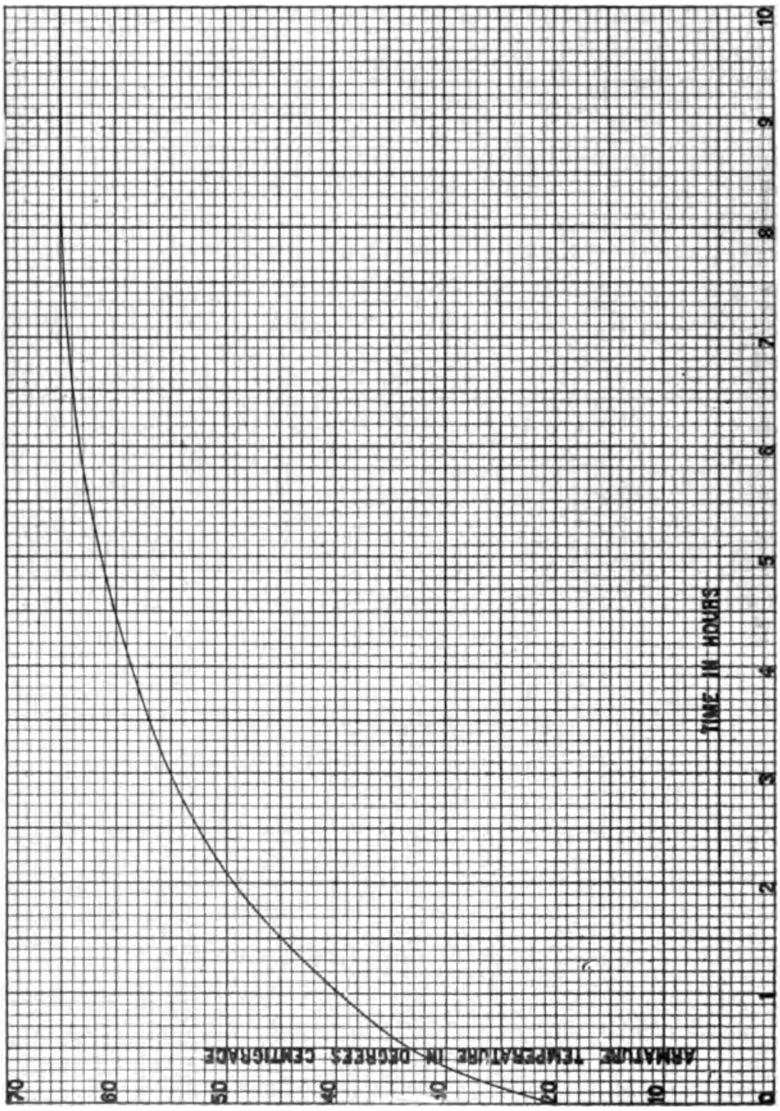

Fig. 38. Rise in Temperature of an Armature of a Large Machine.

care used in its construction, and the care it receives during its operation. Only previous experience with similar machinery is of any value as a guide in this respect.

With proper care and good materials the only defect that is likely to shorten the life of the dynamo is overheating. It is customary to specify that a machine shall be so designed that it may run continuously at full load with a rise of temperature in the armature conductors not exceeding 40° C. above the surrounding air. The commutator may be allowed to reach a slightly higher temperature, say 5° or 10° greater. The effect of overheating is to gradually char and weaken the insulation. This test is easily made after the dynamo has been in operation for a few hours at full load by placing thermometers in the armature windings at the back and front where the windings are accessible and allowing them to remain there about ten minutes covered with waste. In general the above requirement is well within the limits of safety. Fig. 38 is a curve of the rise in temperature of an armature when in operation.

In electric light supply it is very essential that the voltage at the lamps should remain at its proper value. If it is too high the lamps will be unpleasantly bright and their life will be much shortened; if too low the lamps will burn too dimly. If short, quick variations occur, even though very small the effect will be noticed in the lamps as flickering. Hence, it is desirable that the engine driving the dynamo should regulate its speed with extreme closeness. Flickering is avoided by the use of a sufficiently heavy fly-wheel, whose proportion will depend on the speed, point of cut off, and length of stroke. It is usual to specify that the variation in speed of the combination of engine and dynamo from no load to full load shall not exceed 3%, and the change in speed during each stroke of the engine must not exceed one per cent so that flickering in the lamps will not be noticeable.

A characteristic curve should always be taken as well as a speed curve, and if the machine is over-compounded to keep the voltage constant at some particular point on the feeder system, a curve for this point should be constructed by subtracting the volts lost in the mains from the external characteristic curve.

Multipolar machines can be built to run sparklessly under sudden variations in load as great as from no load to full load, and tests should be made by repeatedly throwing on and off certain proportions of the load, and noting the amount of sparking. It is needless to say that under a steady load the machine should run sparklessly. In many machines the position of the brushes depends somewhat on the load and requires shifting with the load.

If an insulation resistance test is made, it should be done when the machine is hot, and a source of electrical energy at considerably higher voltage than that for which the machine is built should be used, generally from 5 to 10 times as great. One pole is applied to the iron core and the other to the armature winding; if the insulation resists this test, no puncture being formed, it is without doubt free from any defect.

The efficiency of any machine is expressed by the ratio of the energy that it gives out, or output, to that which is supplied to the machine or input. This ratio multiplied by 100 gives the percentage efficiency. If the efficiency of a dynamo is 85 %, then 85 % of the mechanical energy supplied to the machine at the pulley, will reappear as available electrical energy at the terminals, while 15 % is lost. The losses are both mechanical and electrical. The mechanical losses are simply the result of friction in the bearings and brushes besides air friction due to the revolving armature. The electrical losses are due to the resistance of the armature and fields, being equal to the square of the current multiplied by the resistance. There are also additional electrical losses from eddy currents and hysteresis.

To determine the total or commercial efficiency there are several methods, mechanical and electrical, in use. If the machine is run from a belt and shaft a dynamometer can be used. There are many different forms of these machines in existence, the principle underlying them being to pass the pull of the driving power through some form of spring which is bent proportionately, the amount of the force exerted being indicated by a pointer on a scale which can be graduated to read in pounds pull. Knowing the pull applied at the circumference of the dynamo pulley, its radius, and the number of revolutions per minute, the horse-power supplied to the dynamo is found by the formula

$$\text{H. P.} = \frac{2 \pi n F r}{33.000},$$

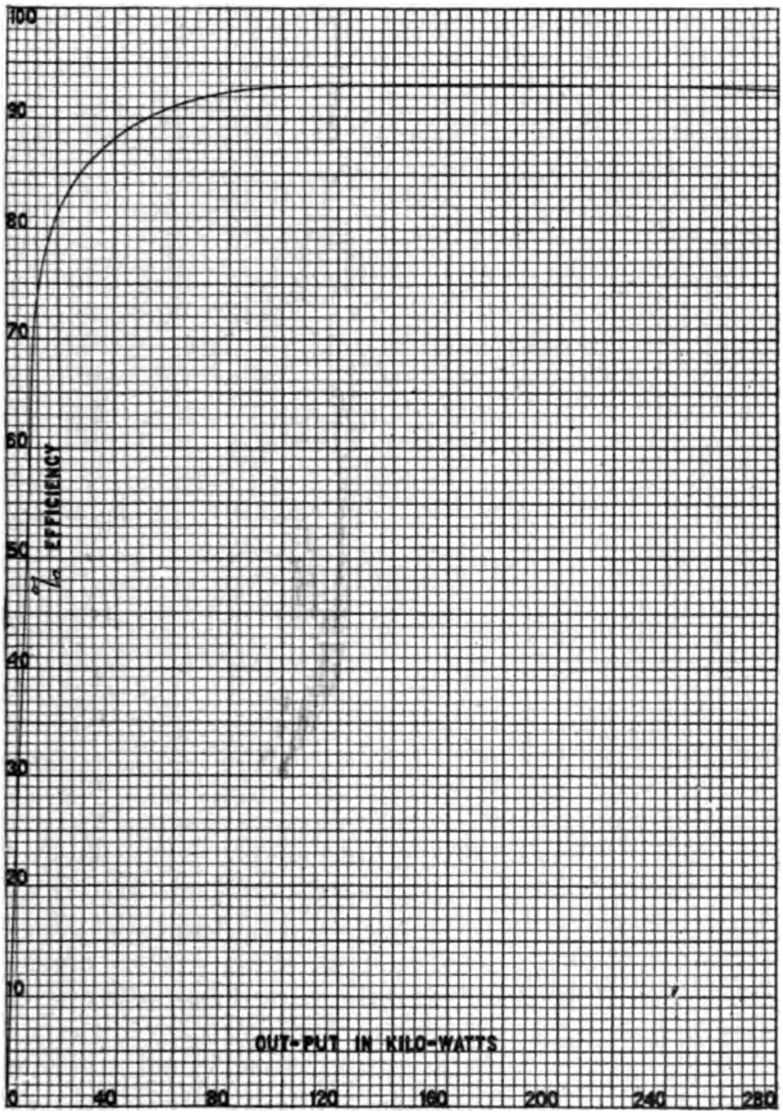

Fig. 39. Efficiency Curve of 200 K. W. Dynamo.

where n is the number of revolutions per minute, F the pull in pounds at the circumference, and r the radius of the pulley in feet.

Knowing the horse-power supplied and the horse-power taken out as given by the product of the current times the terminal voltage divided by 746, the commercial efficiency of the machine in per cent is obtained by multiplying the ratio of the latter result to the former by 100.

The efficiency is of course very much lower at light loads than at full load because friction is practically a constant quantity for a machine running at constant speed, so that the energy consumed by it bears a much greater proportion to the input at low loads than at high.

An efficiency curve of a Crocker-Wheeler direct connected multipolar 200 K. W. machine for lighting purposes is shown in Fig. 39.

It is not always possible to use a dynamometer, as for instance in the case of a direct connected machine. Under these circumstances the best method is to drive the dynamo as a motor with no load, and note the current required to just keep the machine moving at normal speed. This current multiplied by the voltage at the terminals gives the wasted power. The losses at full load are greater since the current is greater, and the $I^2 R$ losses then have a larger value.

With direct current machinery it is sometimes convenient to take indicator cards on the steam engine from which the steam power developed can be calculated, and at the same time to note the electrical output at the switchboard, the ratio of the two giving the efficiency of the combination. This procedure is only permissible when the load is quite steady; any attempt to do this on a railway generator in service is out of the question, because owing to the fly wheel sudden changes of load are not felt simultaneously in the engine and dynamo. A momentary drop of 30% or 40% in the electrical load would probably not reduce the indicated horse-power in the engine at all for a short space of time; the power thus liberated would go into speeding up the fly wheel.

The best method for obtaining a steady load on a dynamo is to pass the current through a water resistance or rheostat consist-

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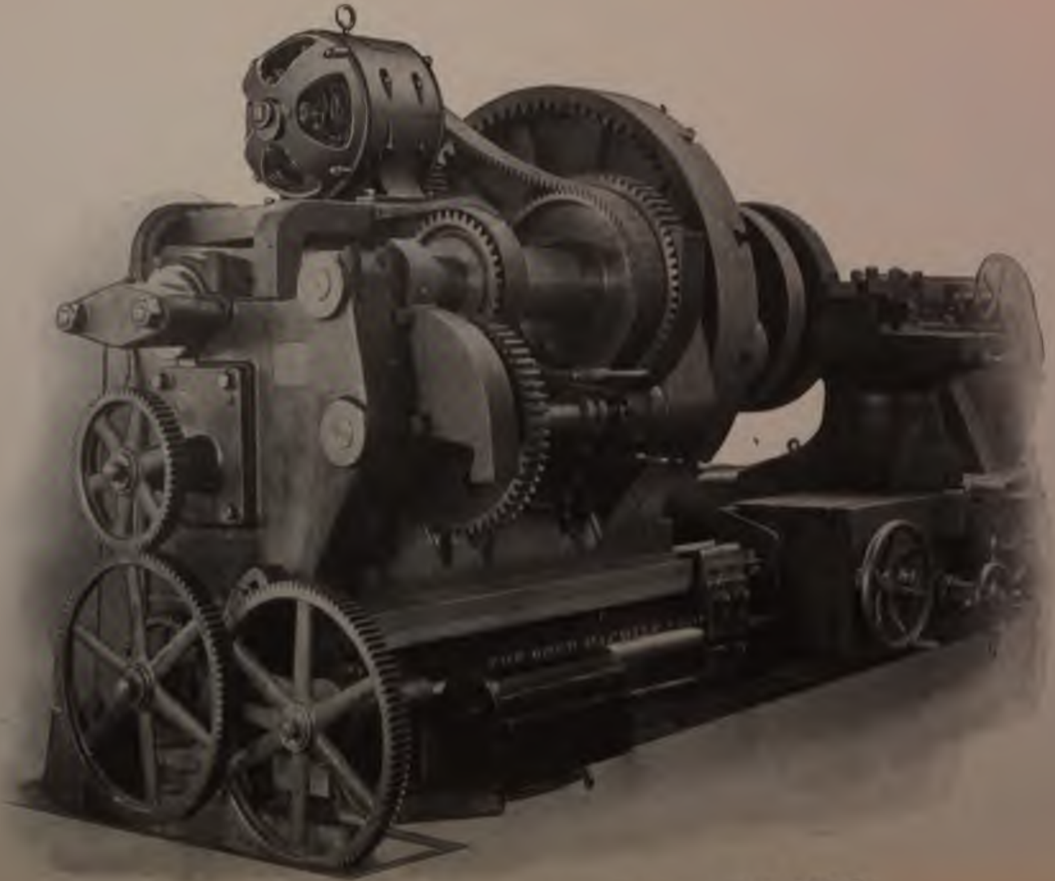
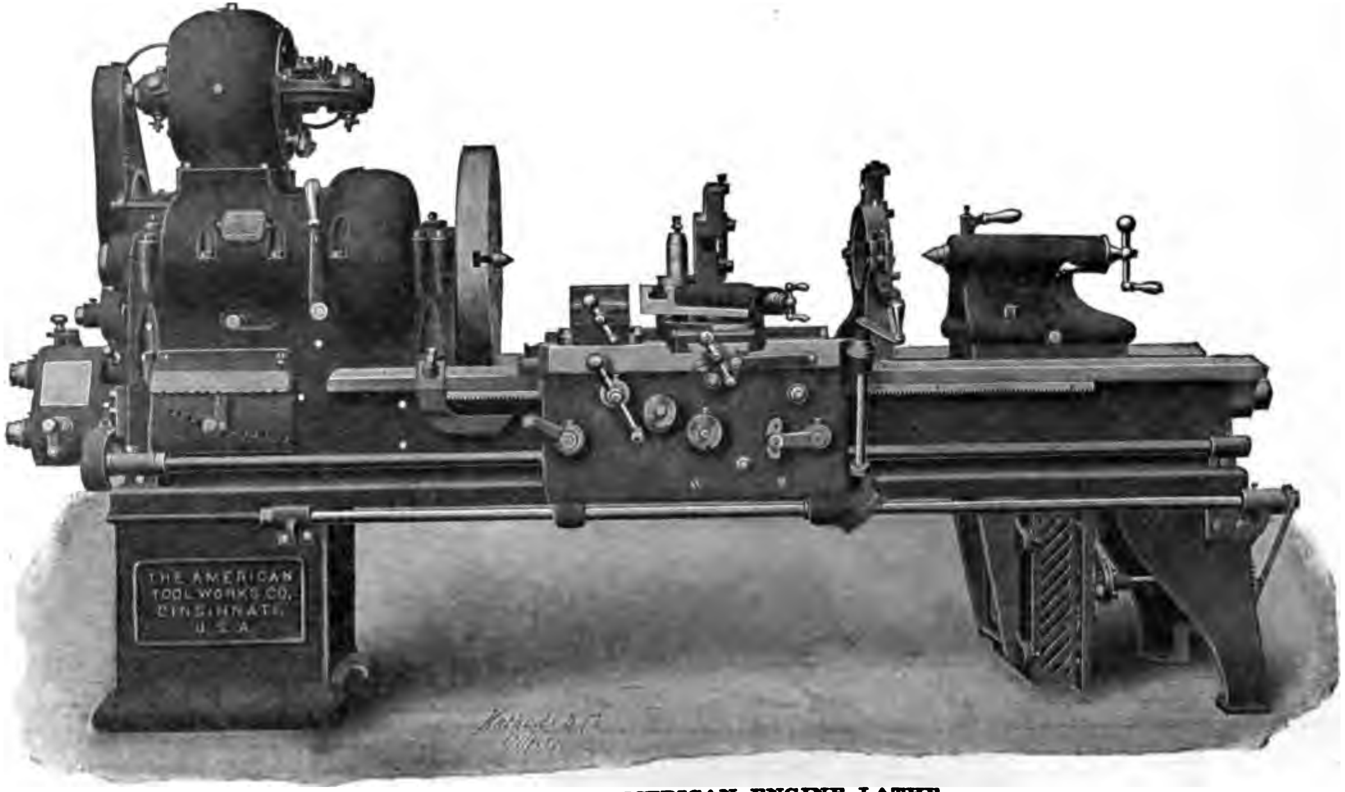


72-INCH LATHE DRIVEN BY 15 H.P. THOMPSON-RYAN MOTOR.

250–1750 Rev. per Minute.

ing of a wooden tank filled with water in which hang two iron plates. The terminals of the dynamo are connected with the iron plates, and the resistance and consequently the load is varied as desired by bringing the plates closer together or moving them farther apart. An arrangement which answers the purpose very well can be made from an ordinary barrel with 4 positive plates and 4 negative plates 12" x 24" and $\frac{1}{16}$" thick, held apart by narrow boards 1" thick placed between them. These boards should be made longer than the plates, so that they can be nailed together above and below. Ordinary furnace grates will also do very well.

Regulation can be secured by suspending the plates by some means above the barrel. They may then be lowered into the barrel to any desired depth. A cold-water supply should be furnished at the bottom of the barrel and an overflow pipe at the top. In this way the water can be carried away as fast as it is heated by the passage of the current. This apparatus will take care of 100 amperes at 550 volts. By adding a handful of salt to the water its capacity can be increased to 300 and even 400 amperes, but at such high values the ebullition is likely to become so great as to be unmanageable.



MOTOR-DRIVEN AMERICAN ENGINE LATHE.

DIRECT CURRENT MOTORS.

GENERAL DISCUSSION.

It has been shown that by means of a **generator** mechanical energy is converted into the electrical form of energy. An electric **motor** is the reverse of this, that is, it converts electrical energy into the mechanical form of energy.

Fundamental Principle. We have learned that when a conductor which forms part of a circuit moves so as to cut lines of magnetic force, a current passes in the conductor, this being the principle of the generator. On the other hand, if a current of electricity passes through a conductor at right angles to lines of magnetic force, the conductor tends to move so as to cut them. This will be made clear by considering Fig. 1. The dots represent lines of magnetic force, their direction being upwards through the paper. *C* represents a conductor that is movable on the rails *A* and *B* which form part of the circuit. The current flowing through *C* causes it to move along the rails to the right or left according to the direction of the current. This is the fundamental principle of the motor.

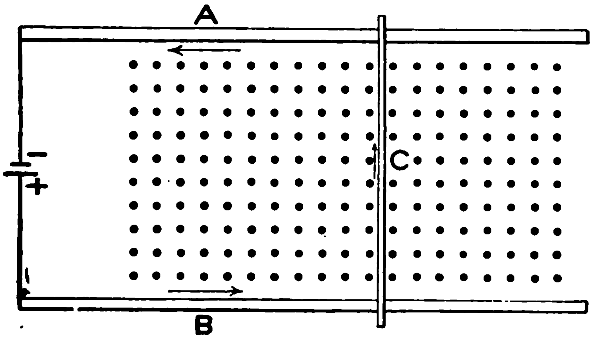


Fig. 1.

Thus we have a means of imparting mechanical motion to a body at the expense of electrical energy.

Direction of Motion. A simple method of obtaining the direction of motion when the direction of the current and of the lines of force are known, is by means of Fleming's rule. In finding the direction of the current in generators the *right* hand is used. In finding the direction of motion of motors the *left* hand is used. The thumb, forefinger, and middle finger of the left hand are held at right angles to each other; then if the forefinger shows the direction of the lines of force, and the middle finger the direction of the current, the thumb will show the direction of motion.

By applying this rule to the case shown in Fig. 1 it appears that the motion of *C* will be to the right. If the current was in the opposite direction *C* would move to the left. If the direction of the lines of force was downward through the paper, the direction of current remaining as represented, *C* would move to the left. If both the direction of current and lines of force were opposite to that represented in Fig. 1, then by the rule it is evident that the motion of *C* will still be to the right.

Interchangeability of Motors and Dynamos. There is essentially no difference between a motor and a dynamo. In fact dynamos usually may be run as motors or motors may be run as dynamos. If a current is passed through the armature of a dynamo we have the conditions for a motor, and the armature will rapidly rotate.

In view of these facts it is evident that nearly all that has been said in regard to generators, applies equally well to motors. Therefore in this section it is only necessary to consider the special characteristics of the latter.

Motion of the Armature. Fig. 2 represents a ring armature which is supplied with a current of electricity from some external source. The direction of the lines of force of the field is from right to left. The direction of the current in a ring armature should be taken as that in the wire on the outside, because the wire on the outside of the ring cuts a greater number of lines of force than the wire on the inside of the ring. Nearly all lines pass through the armature core, as in Fig. 3.

Considering the right-hand half of the ring we see that the direction of the current in the winding on the outside is downward through the paper. By applying Fleming's rule, using the left hand, it is seen that the rotation of the armature will be left-handed. Now considering the left-hand half of the ring (the current in the winding on the outside being upward through the paper) the rotation of the armature is found to be left-handed. Hence each half of the armature causes a left-handed rotation.

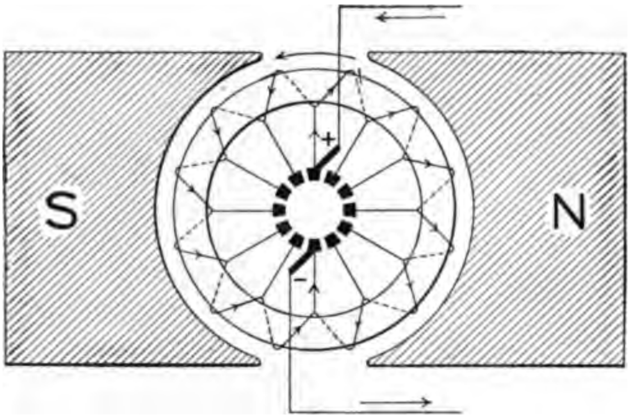


Fig. 2.

Reversal of Rotation. By reversing *either* the direction of the lines of force *or* the direction of the armature current, the direction of rotation will be reversed. If *both* the lines of force and the current are reversed the direction of rotation will be unchanged. These statements may be verified by the application of Fleming's rule to the different cases.

Therefore, the direction of rotation of a motor armature may be changed by reversing *either* the field of force *or* the armature current, but not both.

Generators Run as Motors. By applying Fleming's rule as to the direction of rotation of motors it is easy to determine in what direction the armature of a generator will rotate when run as a motor.

If a series generator is run as a motor the armature will rotate in the opposite direction to that in which it has been driven because both the armature and field currents are reversed; it is, therefore, necessary to reverse the brushes. If the original direction of rotation is desired then either the armature or field connections must be reversed.

The armature of a shunt generator will rotate in the same direction when run as a motor, because while the armature current is reversed the field current has the same direction as when run as a generator.

The armature of a compound generator will have its direction of rotation reversed when run as a motor if the series winding has a greater magnetizing effect than the shunt winding. The direction of rotation will remain the same if the magnetizing effect of the shunt coil is greater than that of the series winding. This will be understood when it is considered that in the generator the field excitation is that due to the *sum* of the magnetizing effects of the shunt and series coils, whereas when run as a motor it is their difference. Of course reversing the connections of either the series or shunt winding would then cause the field excitation to be that due to their sum, the direction of rotation depending upon which connections were changed. If the connections of the series coil were changed the direction of rotation would remain as before; changing the connections of the shunt coil would reverse the rotation.

Counter Electromotive Force. We have learned that when a conductor moves across lines of magnetic force, an E. M. F. is generated in the wire, and that this is the fundamental principle of the dynamo. Now, when the armature of a motor is caused to rotate, by passing a current through it, the very act of moving across the field of the motor causes the generation of an E. M. F. This E. M. F. is opposed to that applied to the motor and is known as the *counter* E. M. F.

The greater the speed of the armature, the greater will be this counter E. M. F., as a larger number of lines of force are cut in a given time. Also the greater the counter E. M. F. the less will be the drop of potential in the armature, for the effective E. M. F. is reduced as the counter E. M. F. increases. The strength of the armature current will therefore depend upon the speed. When the armature is forcibly restrained from rotating, the current is at its maximum, being equal to the E. M. F. applied at the brushes divided by the resistance. On releasing the armature, the strength of the current gradually decreases as the motor comes up to speed.

Motor Equation. The drop of potential in a motor armature is equal to the applied E. M. F. minus the counter E. M. F. Hence from Ohm's law, we have,

$$I = \frac{E - e}{r}$$

where I is the armature current, E the E. M. F. applied at the brushes, e the counter E. M. F., and r the armature resistance. This is the fundamental *motor equation.*

From this equation it is evident that when e is small, that is, before the motor is up to speed, the armature current will be large. As the speed increases the counter E. M. F. is increased causing the current to become less and less until at full speed the current is normal.

Example.—The armature resistance of a motor is .54 ohm, the E. M. F. at the brushes is 215 volts, and the counter E. M. F. is 190 volts. What current passes through the armature?

Solution.—By the motor equation,

$$I = \frac{215-190}{.54} = 46.3 \text{ amperes (nearly).}$$

Ans. 46.3 amperes.

Example.—If the armature current is 14.1 amperes, the voltage at the brushes 109 and the armature resistance 1.69 ohms, what is the counter E. M. F.?

Solution.—Substituting in the motor equation,

$$14.1 = \frac{109 - e}{1.69}$$

$$e = 85.2 \text{ volts (approx.).}$$

Ans. 85.2 volts.

The Distortion of Field which occurs in a dynamo is also present in a motor, being due to the fact that the lines of force of the armature field are nearly at right angles to those of the field magnets, the amount of distortion being dependent upon the relative strength of the two fields.

In a motor the direction of the armature current and consequently the direction of its field is opposite to that in a dynamo. This causes the resultant field of a motor to be as represented in Fig. 3. It is evident that the neutral points are shifted *backwards*, whereas in the generator they are shifted forwards. This figure should be compared with the corresponding one for a dynamo, Fig. 35, in the section devoted to *Theory of Dynamo-electric Machinery.* Hence, to place the brushes at the neutral point of a motor they are shifted in an opposite direction to that of rotation. The greater the armature current the greater will be the distortion of field, and the more the brushes must be shifted backwards.

If the field magnets are made very powerful as compared with the armature, the distortion of field will be very slight or will be practically absent. In that case the brushes need not be shifted for variations in the load.

As seen in Fig. 3 the density of the lines of force is greater at the horns A, which the armature is approaching, than at the horns *B*, from which it is receding; consequently the induced Foucault currents and the heating will be greater in the horns *A*, while in the generator the heating is greater in the horns from which the armature is receding. In the case of the motor the air current tends to equalize the difference of temperature between the horns *A* and *B*. because cool air is drawn in at *A* and ejected somewhat warmer, at *B*; whereas in the generator cool air is drawn in at the cooler horns which tends to increase the difference of temperature.

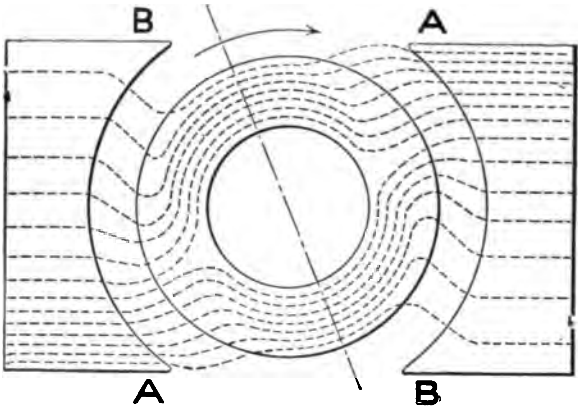


Fig. 3.

Efficiency. The *commercial efficiency* of a motor is equal to the actual output divided by the actual input, or

$$\textit{commercial efficiency} = \frac{\textit{output}}{\textit{input}}.$$

Or $$\textit{commercial efficiency} = \frac{\textit{input} - \textit{losses}}{\textit{input.}}.$$

The losses in a motor may be given under two heads:

The **electrical** losses,

(*a*) Armature wire I^2 R loss.
(*b*) Field wire I^2 R loss.

The **stray power** losses,

(*c*) Friction of bearings.
(*d*) Friction of brushes.
(*e*) Friction due to air resistance.
(*f*) Waste currents in coils during commutation.
(*g*) Foucault currents in armature core.
(*h*) Hysteresis in armature core.
(*i*) Foucault currents in armature wire.
(*j*) Foucault currents in pole pieces.

The electrical losses in the field and armature windings are due to the heating of the conductors by the current flowing through them. This loss as we have learned varies directly as the square of the current and as the resistance, that is, as $I^2 R$.

The stray power losses are small when considered separately, excepting friction of bearings, but collectively they usually amount to as much as the electrical losses. The stray power losses are practically constant for any load.

The *electrical efficiency* is the efficiency of the motor when only the electrical losses *a* and *b* are considered. This may be expressed as the input minus the electrical losses, divided by the input, or

$$\textit{electrical efficiency} = \frac{\textit{input} - \textit{electrical losses}}{\textit{input}}.$$

The electrical efficiency, therefore, only indicates the amount of the electrical losses and does not take into account the stray power losses.

The *efficiency of conversion* or *gross efficiency* of a motor is the ratio of the output to the useful electrical energy or to the input minus the electrical losses, that is,

$$\textit{gross efficiency} = \frac{\textit{output}}{\textit{input} - \textit{electrical losses}}.$$

The gross efficiency, therefore, takes into account only the stray power losses.

When no efficiency is specified, the commercial efficiency is understood.

The commercial efficiency of small motors ranges from 50% to 75%. Motors of from three to ten horse-power have efficiencies which range from 75% to 85 %. Larger motors should have an efficiency in the neighborhood of 90%.

Example.—A motor has at its terminals an E. M. F. of 220 volts, and takes a current of 26 amperes. The output is 5.94 horse-power; what is the efficiency of the motor?

Solution.—Input $= 220 \times 26 = 5720$ watts.

$$= \frac{5720}{746} = 7.67 \text{ H. P. (approx.)}$$

$$\text{Efficiency} = \frac{5.94}{7.67} = .774 + \text{ or } 77.4 + \%$$

Ans. 77.4 + %

Siemens' Law of Efficiency. This law is as follows: The efficiency of a motor is equal to the ratio of the counter E. M. F. to the applied E. M. F.

This law assumes that the only loss existing is that in the armature wires, or $I^2 r$, where I is the armature current and r the armature resistance. Hence it is assumed that there are no stray power losses, and also that we have a magneto motor.

The proof of the law is as follows:

$$\text{Efficiency} = \frac{input—losses}{input}.$$

$$\text{Input} = E\,I.$$

$$\text{Losses} = I^2\,r.$$

Hence,

$$\text{Efficiency} = \frac{E\,I - I^2\,r}{E\,I}$$

$$= \frac{E - Ir}{E}$$

By the motor equation

$$I = \frac{E - e}{r}, \text{ then } Ir = E - e.$$

Therefore,

$$\text{Efficiency} = \frac{E - (E - e)}{E}$$

$$\text{or, Efficiency} = \frac{e}{E}.$$

That is, the efficiency is equal to the counter E. M. F. divided by the applied E. M. F.

Hence the greater the counter E. M. F. the higher the efficiency of the motor. If the counter E. M. F. could become equal to the applied E. M. F., the efficiency would be equal to unity, or 100 per cent, but in that case no current would pass in the armature and consequently there could be no output.

Jacobi's Law of Maximum Output. This law may be stated as follows: The maximum amount of work is done by a motor when the speed is such that the counter E. M. F. is one-half of that applied to the motor.

The proof of this law is most easily understood by the aid of a diagram. Fig. 4 represents a square having the length of the side equal to E, the applied E. M. F. The distance $A\ B$ is equal to e, the counter E. M. F. The diagonal is drawn from A, and the horizontal from B. At the point where this crosses the diagonal, a vertical is drawn. The distance $B\ C$ is evidently equal to $E - e$.

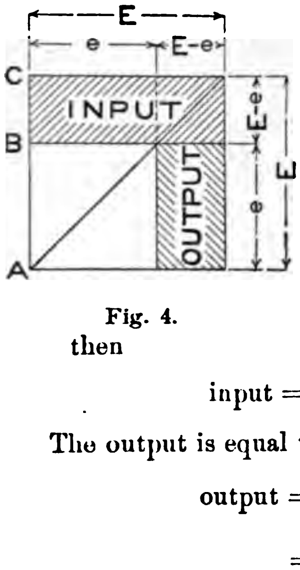


Fig. 4.

The input is equal to $E\ I$, and as

$$I = \frac{E - e}{r},$$

then

$$\text{input} = E\ I = \frac{E\ (E - e)}{r}.$$

The output is equal to the input minus the losses, that is,

$$\text{output} = \frac{E\ (E - e)}{r} - I^2\ r$$

$$= \frac{E\ (E - e)}{r} - \left\{ \frac{E - e}{r} \right\}^2 r$$

$$= \frac{E\ (E - e) - (E - e)^2}{r}$$

$$= \frac{e\ (E - e)}{r}.$$

In these values of output and input a constant, r, appears in the denominator of each, therefore the relation of the output and input will be as the magnitude of the numerators. That is, we may represent output by $e\ (E - e)$, and input by $E\ (E - e)$. Referring to the figure, it is evident that the area of the rectangle *output* is equal to $e\ (E - e)$; that of the rectangle *input* is equal to $E\ (E - e)$.

Now if in Fig. 4 the counter E. M. F. is decreased the output will increase until it becomes a square, and will evidently then have a maximum value as shown in Fig. 5. The counter E. M. F. is then one-half the applied E. M. F. Hence the maximum amount of work is done by a motor when the counter E. M. F. is one-half of that applied.

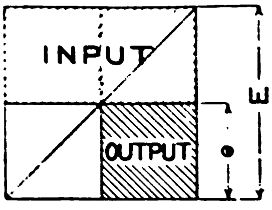


Fig. 5.

When a motor is doing a maximum amount of work the value of the current, as found by the motor equation, is one-half of that which would pass when the motor is at rest, that is, when no counter E. M. F. is generated.

It is evident from Fig. 5 that when the output is a maximum it is equal to one-half the input, consequently the efficiency is then 50%. This is also seen to be true from Siemens' law because e is one-half E, hence the efficiency is equal to 50%.

On account of the assumptions which must be made in the proof of these laws they are not strictly followed in practical machines.

Torque. The torque of a motor is its tendency to turn. It is usually expressed in pound-feet, and is equal to the pull in pounds exerted at one foot radius.

If it is known that a certain number of pounds pull is exerted at the circumference of a pulley whose radius is known, the torque is obtained by multiplying the pounds pull by the radius in feet. On the other hand, if the torque is known the pull at any radius is found by dividing by the radius.

The number of foot-pounds of work done by one revolution of a shaft is equal to the torque multiplied by $2\ \pi$, for $2\ \pi$ is the circumference in feet of a circle of one foot radius, and torque is the pounds pull at that distance, hence the product of the pounds pull and distance through which it acts gives the work done. If there are n revolutions per minute, the foot-pounds of work done per minute will be $2\,\pi\,n\,T$, where T is the torque; hence the horse-power will be

$$\text{H. P.} = \frac{2\,\pi\,n\,T}{33{,}000}.$$

If the horse-power and number of revolutions are known, the torque may be found from the formula

$$T = \frac{\text{H. P.} \times 33{,}000}{2\,\pi\,n}.$$

If the torque and the horse-power are known, the number of revolutions may be found from the formula

$$n = \frac{\text{H. P.} \times 33{,}000}{2\,\pi\,T}.$$

In a given armature, the torque varies directly as the product of the field strength and armature current, or

$$T \textit{ varies as } f\,I$$

where T is the torque, f the field strength, and I the armature current. That is, if the field is kept constant the torque will vary directly as the armature current, and if the latter is kept constant the torque will vary directly as the field strength.

Measurement of Torque. The Prony brake may be used to measure the torque of a motor. The arrangement is shown in Fig. 6. P is a pulley on the armature shaft; the blocks A and C bear against the face of the pulley, the pressure being regulated by the wing-nuts e. The lever L which is clamped to A, is counterbalanced by the weight w. The weight W which is supported by

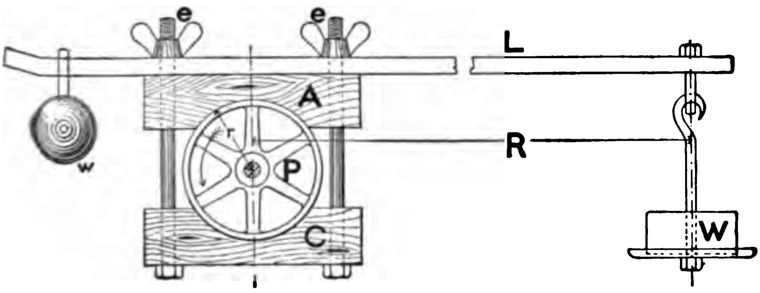


Fig. 6.

the lever has such a value as will keep the lever horizontal when the pulley is rotating.

To find the torque at a certain speed or when the motor take a certain current, the pressure on the pulley is adjusted until the speed or current is that desired. The weight W is made to balance the tendency of the lever to turn. The torque is then found by multiplying the measured distance R in feet, by the weight W in pounds.

Example.—In finding the output of a motor the distance R was 2.5 feet, the weight W was 12.4 pounds, and the number of revolutions of the motor was 1,400 per minute. What was the output of the motor in horse-power?

Solution.— Torque = 2.5 × 12.4 = 31. pound-feet.

$$\text{H. P.} = \frac{2\,\pi\, n\, T}{33{,}000}$$

$$= \frac{2 \times 3.142 \times 1{,}400 \times 31}{33{,}000}$$

$$= 8.25 + \qquad \text{Ans. } 8.25 + \text{H. P.}$$

Example.— What pull at the rim of a pulley 10 inches in diameter will be given by a 6 H. P. motor running 1,200 revolutions per minute?

Solution.— $$\text{T} = \frac{\text{H. P.} \times 33{,}000}{2\,\pi\, n}$$

In this case H. P. = 6. $n = 1{,}200$.

Therefore

$$\text{T} = \frac{6 \times 33{,}000}{2 \times 3.142 \times 1{,}200} = 26.2 + \text{pound-feet.}$$

But T = pounds pull × radius in feet.

$= \text{pounds pull} \times \frac{5}{12}$

Therefore pounds pull $= 26.2 \times \frac{12}{5} = 62.7$ lbs. (approx.)

Ans. 62.7 lbs.

Speed. To arrive at a general expression which will show upon what factors the speed of a motor depends, we shall make use of the motor equation.

$$I = \frac{E - e}{r}.$$

Let s represent the speed of rotation, a the number of conductors on the surface of the armature, f the field strength, and k

a constant. As the E. M. F. generated by an armature moving in a field depends upon the speed, number of conductors, and strength of field, the counter E. M. F. of a motor will be equal to

$$e = s\,a\,f\,k.$$

Substituting this value in the motor equation, we have

$$I = \frac{E - s\,a\,f\,k}{r} \quad \text{or} \quad I\,r = E - s\,a\,f\,k,$$

therefore $s\,a\,f\,k = E - I\,r$, and $s = \dfrac{E - I\,r}{a\,f\,k}$.

The armature resistance of a motor is usually very small, hence the product $I\,r$ would be small and may be neglected.

Therefore the expression for speed may be written

$$s = \frac{E}{a\,f\,k}.$$

From this expression it is evident that the speed varies *directly* as the E. M. F. applied at the brushes if the number of armature conductors and the field strength are constant. An increase in E causes a greater current to pass through the armature, which, acting upon the same field strength, causes an increase of speed, provided the torque exerted is kept constant.

If the number of armature conductors and the applied E. M. F. are constant, the above expression shows that the speed varies *inversely* as the field strength, that is, if the field is weakened the speed is increased or if the field is strengthened the speed is decreased. This is true for if the field is weakened the counter E. M. F. generated by the motor will be less allowing a greater current to pass in the armature. This will tend to increase the torque but if that is kept constant, the speed will increase, a higher speed being now required to generate the same E. M. F. as was the case when the field was stronger.

If the field strength and applied E. M. F. are constant, the speed varies *inversely* as the number of armature conductors, that is, a decrease in the number of armature conductors increases the speed. If a reduction is made in the number of conductors the motor must evidently run at a higher speed in order to generate the same counter E. M. F. as before, the torque being kept constant.

Windings of Motors. As in the case of a dynamo the common windings of a motor are shunt field winding, series field winding and compound field winding.

The motor may be supplied with electrical power at a constant potential or the current may be constant.

SHUNT MOTORS ON CONSTANT POTENTIAL CIRCUITS.

Torque. As the torque of a motor with a given armature varies as the product of the armature current and field strength, if the field strength is constant the torque will vary directly as the strength of the armature current. The shunt motor on a constant potential circuit will have a constant current passing through the field coils, consequently the field strength will remain constant, and the torque will vary only as the strength of the armature current.

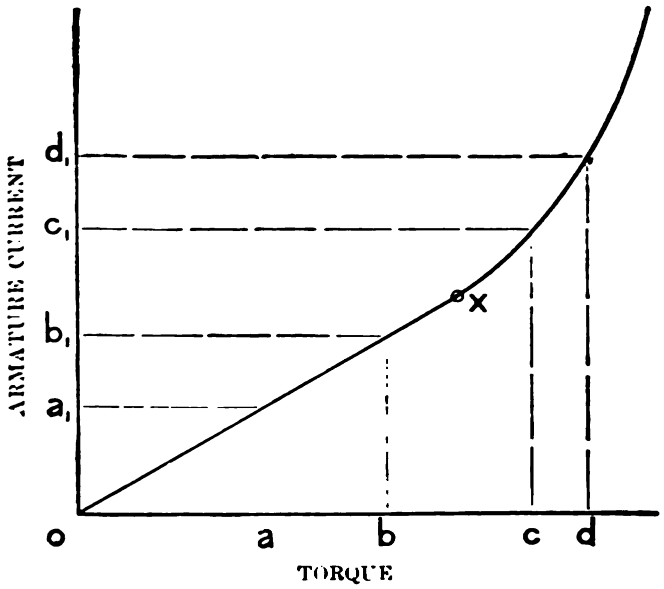
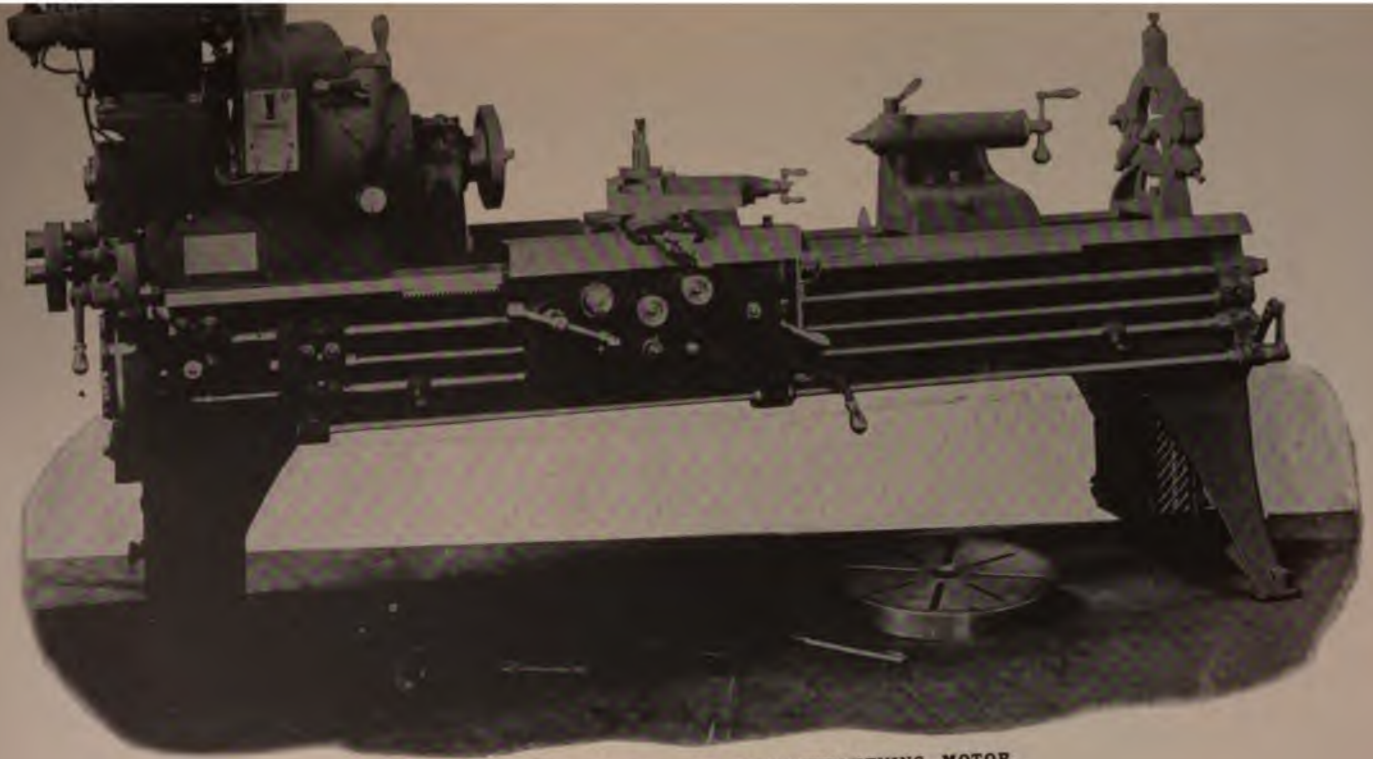


Fig. 7.

This is represented by the torque curve in Fig. 7. In this plot the abscissae *o a*, *o b*, *etc.*, represent the torque and the



LATHE WITH SINGLE-VOLTAGE FIELD-WEAKENING MOTOR.

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nates $o\ a_1$, $o\ b_1$, *etc.*, the armature current, that is, when the ue has a value represented by $o\ a$ the corresponding value of rmature current will be $o\ a_1$. It is evident that from o to point x the plot is a straight line, an increase in the armature ent causing a proportional increase in the torque. Beyond t x the line is curved this being due to distortion of field by large armature current. Here a considerable increase in the ent as $c_1\ d_1$ produces but a small increase $c\ d$ in the torque. ood machine should not have much distortion of field at or er normal load.

Constant Speed. The speed of a shunt motor on a constant ntial circuit is practically constant for any load.

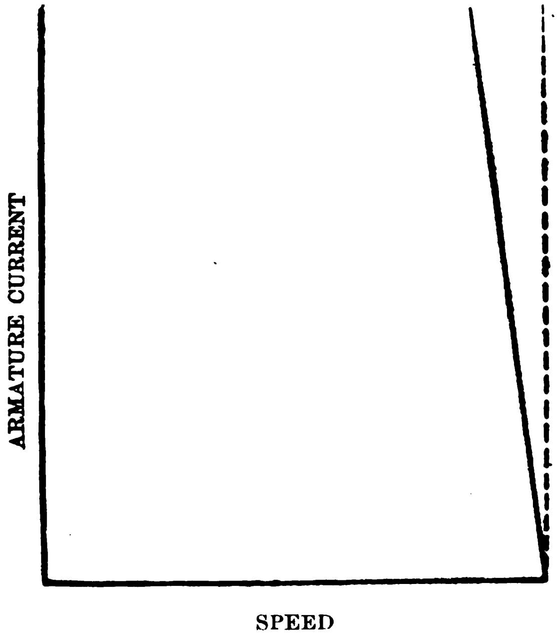

Fig. 8.

This is seen to be true from our approximate expression for d,

$$s = \frac{E}{a f k}.$$

since E is constant. f will be constant, and in a given arma- a will be constant, therefore s will have a constant value.

As a matter of fact the speed will fall *slightly* as the torq increases. An increase of torque causes the armature current be greater. As the applied E. M. F. is constant the increase the armature current can only occur by decreasing the coun E. M. F., this being evident from the motor equation. Then i decrease in the counter E. M. F. is necessary the speed must slightly less.

This is represented in Fig. 8, which shows a gradually f ing speed as the armature current is increased. In the figure, indicated, the abscissae represent the speed, and the ordinates armature current.

There are many methods of varying the speed of a sh motor, all of which depend upon the variation of E. M. F. appl at the brushes, variation of field strength, or variation in the n ber of armature conductors. We will consider these methods detail.

Variation of E. M. F. at the Brushes. We have seen t the speed of a motor varies directly as the E. M. F. applied the brushes.

If a resistance is connected in series with the armature th will be a certain number of volts lost by the armature curr passing through this resistance, consequently the voltage at brushes will be less and the speed creased. This method is illustrate Fig. 9, the resistance *R* being inser in the armature circuit. The com tator is represented by *C*, and the sh field windings by F. The greater resistance inserted the less will be speed.

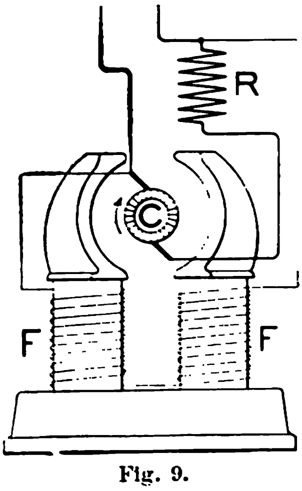

Fig. 9.

Problem. — Suppose a shunt mo is to be used on a 220 volt circuit, current taken by the armature at load being 16 amperes and the sp 1,000 revolutions per minute. It desired that the motor should run a speed when the torque is $\frac{3}{4}$ of that full load. What resistance *R*, is it then necessary to insert the armature circuit?

Solution. — Here $E = 220$, the normal current $I = 16$, and the speed $s = 1{,}000$ revolutions per minute.

We have seen that the expression for the speed of a motor is

$$s = \frac{E - Ir}{a\,f\,k},$$

and, as only the voltage E is to be varied, the denominator $a\,f\,k$ is a constant. Hence the formula may be written

$$s = \frac{E - Ir}{\text{constant}}.$$

As the resistance R is in series with r, and as r is very small we can neglect it. With R inserted the formula becomes

$$s = \frac{E - IR}{\text{constant}}.$$

The value of the denominator is easily found, for, when R is cut out of the circuit, $IR = 0$, and the speed is normal being 1,000 revolutions. Substituting these values in the equation we have

$$1{,}000 = \frac{220 - 0}{\text{constant}}$$

$$\text{constant} = .220.$$

Hence

$$s = \frac{E - IR}{.220}.$$

The torque is to be $\frac{3}{4}$ of that at full load, and as the field strength is constant the torque is decreased by decreasing the armature current I. Hence at $\frac{3}{4}$ torque the current will be $\frac{3}{4}$ of that at full load or $\frac{3}{4} \times 16 = 12$ amperes. The speed is to be $\frac{1}{2} \times 1000 = 500$ revolutions per minute.

Substituting these values in the preceding equation we obtain

$$500 = \frac{220 - 12\,R}{.220}.$$

Therefore $R = 9.17$ ohms nearly.

Ans. 9.17 ohms.

The above method of regulating the speed of a shunt motor is the one most largely used, being simple and perfectly controlling the speed at all loads. It has the disadvantage, however, of po economy, because the energy lost as heat in the resistance is co siderable, being equal to I^2R.

The resistance used for starting the motor (see page 2 must not be used for regulating the speed in the above way. T starting resistance is usually very compact, and has a relativ small surface exposed to the air. It does not heat much duri the short time required for starting, but if allowed to carry t armature current continuously it is liable to burn out. Regul ing resistances are often made of zigzag strips of iron, insula with asbestos, and exposed as much as possible to the air.

Variations of Field Strength. It has been shown that increase in the speed of a motor is obtained by weakening the fi strength, and that a decreased speed is obtained by increasing t field strength.

A simple and much used method of varying the field stren is the insertion or cutting out of resistance in the field circ This will change the current passing in the field coils and con quently the magnetization of the field magnets.

Another method of changing the magnetizing force is by h ing part of the field windings of German silver, and by cutt them in or out, the field strength is varied. As German silver a high resistance the addition of these coils increases the resista in greater proportion than the number of turns, so decreasing ampere-turns. This method allows a moderate variation in spe is easily operated, and is not expensive.

The objections to any method of regulating the speed by va ing the field strength are:

1. If the speed is decreased the torque remaining consta the motor gives out less power but requires at the same time increased expenditure of energy in the fields.

2. It is customary in order to get the full power of a mo to have the field magnets at or near the point of saturation normal speed. But if it is desired to run the motor at a slo speed, the fields must be below their point of saturation at nor speed, since to decrease the speed the field strength must be creased. Hence at normal speed the fields are not worked to th full capacity, and the full power of the motor is not utilized. T is, the motor is larger than it otherwise would be, which means additional expense.

3. When the fields are weakened to increase the speed, the armature current causes greater distortion of the field and sparking is greatly increased.

If the resistance of the magnetic circuit is varied, the field strength will also be changed, and an increase of the magnetic resistance will cause an increase in the speed. This method of controlling the speed is not only usually difficult to apply but is also uneconomical. The magnetic resistance can be varied in three different ways: (*a*) the lines of force passing through the armature can be diverted through a movable piece of iron placed near the pole pieces, (*b*) the length of the air gap can be varied by having the relative position of field magnets altered, and (*c*) the cross section of the air gap can be varied by changing the relative position of the armature and pole pieces.

Variation of Number of Armature Wires. We have seen that the speed may be expressed approximately

$$s = \frac{E}{a\,f\,k}.$$

If the armature is arranged so that every two wires can be connected in multiple the number of conductors will then be equivalent to $\frac{a}{2}$ having $\frac{1}{2}$ the resistance. This change will cause the new speed s' to be double the speed s. For

$$s' = \frac{E}{\frac{a}{2} f k} = \frac{2\,E}{a\,f\,k},$$

which is twice the value of s.

If every two wires are again connected in multiple the number of conductors is $\frac{a}{4}$, the speed then being 4 s.

The same result is obtained in practice by changing two or more independent windings from series to multiple. These windings may be on the same armature core, or on separate cores on the same shaft, each winding requiring a separate pair of brushes.

The same result may be obtained by coupling separate motors to the same work.

Fig. 10 represents the changes where there are four independent armature windings or four independent motors. The separate commutators are represented by *c* and field windings by *f*, the connections of the latter being the same for all speeds. In case *A* the brushes, and hence the armature windings are connected in series.

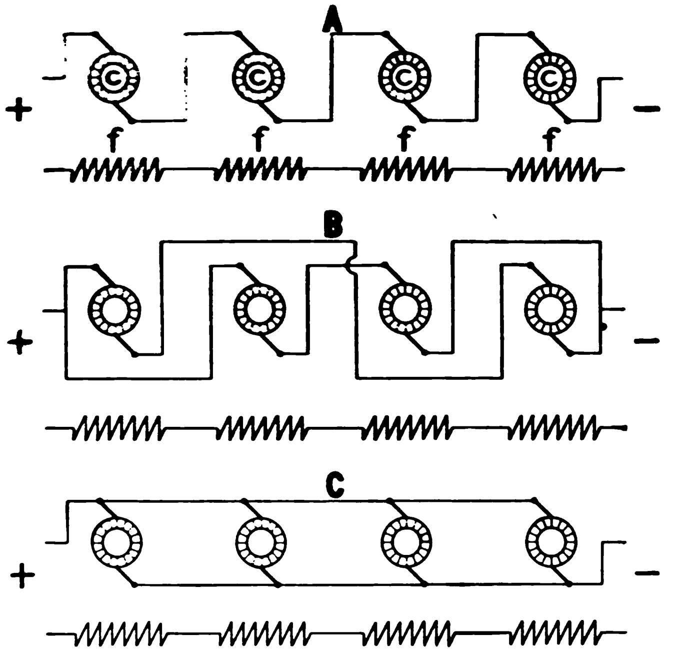

Fig. 10.

The number of armature windings being large the speed is small. In case *B* the armatures are connected in series multiple. The number of windings being then equivalent to ½ of the number in the first case, the speed will be twice as great. In case *C*, the windings are all connected in multiple, hence the speed will be four times that in case *A*, and twice that in case *B*. We have, therefore, in case *C* full speed, in case *B* ½ speed, and in case *A* ¼ speed.

This method of regulating the speed is satisfactory in regard to efficiency, for, if a constant torque is exerted by the motors throughout the above changes, the current taken by each motor will have a constant value. Hence in case *B* the current used will be twice that in case *A*; but in the former case the speed is twice as great, and although the energy consumed is twice as much, the output is also double. Therefore the efficiency remains unchanged. Similarly the efficiency remains unchanged in case *C*.

The objection to this method is, of course, the use of several motors, which involves extra expense.

Variation of Position of the Brushes. By shifting the brushes from the neutral point the speed of the motor can be increased. This will be understood from Fig. 11.

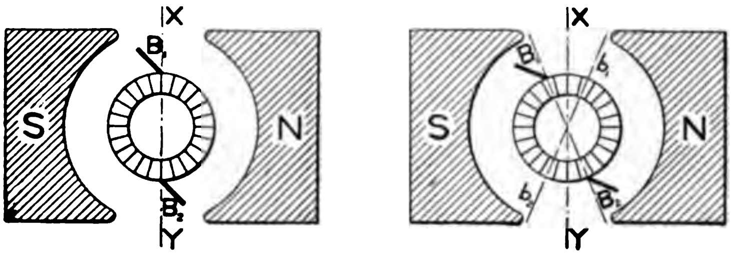

Fig. 11.

The neutral line is represented by *X Y*, and in the left-hand figure the brushes B_1 B_2 are at the neutral point, the entire counter E. M. F. generated, that is, by the conductors from B_1 to B_2, being effective. In the right-hand figure the brushes are shown shifted and in this position the effective counter E. M. F. is reduced. In this case the counter E. M. F. generated by the conductors from B_1 to *X* opposes that generated from *X* to B_2, the effective counter E. M. F. being reduced to that generated by the conductors from b_1 to B_2, and likewise from b_2 to B_1. For constant torque, however, the armature current must be constant when the field strength is not changed, therefore the counter E. M. F. must not be reduced. As a smaller number of conductors are now available to generate the counter E. M. F., the speed of the motor must be increased. That is, by shifting the brushes from the neutral point the speed is made higher.

This method is really equivalent to reducing the number of armature conductors. It has the great objection of causing excessivesparking and of being injurious to the commutator, brushes, and armature winding.

Starting Resistance. If a motor armature is restrained from rotating the current passing through it will be very large, being equal to $\frac{E}{r}$, since no counter E. M. F. is generated. This excessive current would damage the armature, hence it is necessary to have a large resistance in the armature circuit to make the current small while the motor is coming up to speed. That is, before starting a motor, a large resistance should be connected in the armature circuit which is gradually reduced as the motor comes up to speed.

In order not to have the armature current in starting larger than the normal current, the resistance inserted, R, should be $R = \frac{E}{I}$, where E is the applied E. M. F. and I the normal armature current. For motors of more than 15 horse-power, however, R should be greater than $\frac{E}{I}$ in order not to throw a heavy load suddenlyon the driving dynamo.

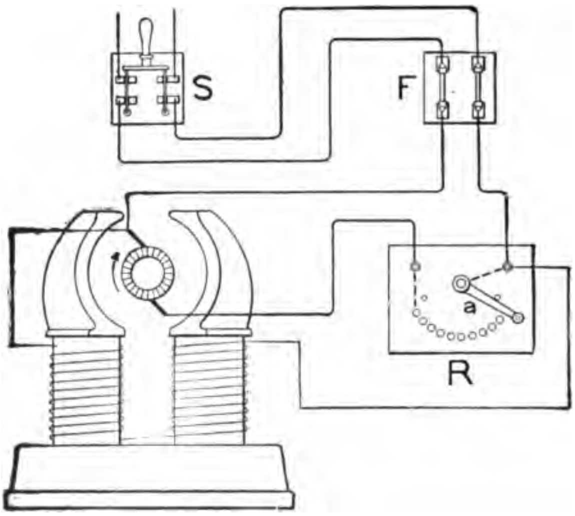

Fig. 12.

Connections. The connections for a shunt motor on constant potential mains are shown in Fig. 12. From the mains the conductors lead to the double pole switch *S*. The fuses *F*, made of an easily fusible metal, are placed on both lines to protect the motor from dangerous currents caused by short circuits. The fuses are of such a cross section that they melt when a current greater than the safe one for the motor passes through them, and so break the circuit. The starting resistance is *R*, and is arranged so that turning the arm *a* will close the armature circuit inserting the full resistance *R*, and then gradually reduce it until it is all cut out. The switch *S* is placed outside the other connections so that when it is opened they are entirely disconnected and may be handled without fear of receiving a shock.

Starting. After making sure that the arm of the starting resistance is in the position so that the armature circuit is disconnected, the switch *S* is closed, and the fields then become fully charged before any current flows through the armature. The armature circuit is then closed through the resistance *R*, and as the motor speeds up this resistance is gradually cut out. As the speed of the motor increases, the counter E. M. F. becomes greater and the armature current less, allowing the resistance *R* to be cut out.

Stopping. In stopping the motor the switch *S* is first thrown. After the motor has come to rest the arm *a* of the resistance is then turned to the position ready for starting.

While coming to rest the motor runs as a generator and the field current is supplied by the armature. The direction of this current being the same as before, its strength will *gradually* decrease as the motor slows down, thus allowing a *gradual* decrease in the field strength.

If the armature circuit is broken first, then on throwing the switch *S* the field current is cut off abruptly, and the high E. M. F. caused by self-induction produces a destructive flash at the switch; moreover a very high potential is produced in the field winding and this is likely to pierce the insulation. Also for this reason the switch should not be closed unless the motor is afterwards started.

Reversing Motors. Motors are reversed in the direction of their rotation by simply changing the relative direction of the magnetic field and the armature current. This, as we have seen is accomplished by changing *either* the direction of the armature current *or* the field current. The former is the more common method. A motor which is to be often reversed should have powerful field magnets so that there will be practically no distortion of the field and no lead will be necessary for the brushes. Otherwise the lead would have to be changed when the rotation is reversed.

Reversing While Running. If the direction of the armature current is reversed while the motor is running, then until the armature comes to a stop and its rotation reversed, the counter E. M. F. acts *with* the applied E. M. F. This would cause the armature current to be extremely large being equal to

$$I = \frac{E + e}{r}.$$

It is therefore necessary that a large resistance R should be inserted in the armature circuit before the current is reversed. Then before the armature stops rotating the current will be

$$I = \frac{E + e}{R + r}.$$

However, as the direction of the armature current is now changed and comparatively large, the armature is quickly brought to rest, the current gradually decreasing as e becomes less and less.

When e becomes zero, that is, when the motor has stopped,

$$I = \frac{E}{R + r}.$$

The motor now speeds up in the opposite direction, e gradually increasing but now opposing E. As the motor speeds up, R is cut out, and the current becomes normal being equal to

$$I = \frac{E - e}{r}.$$

Reversing the direction of the current in the field circuit does not produce so abrupt a change in the motion of the armature, nor does its current become so excessively large. This is so because the field strength does not rise rapidly on account of self-induction and reluctance of the magnetic circuit; the armature then has time to slow down considerably so that the additive e is small, and the current cannot become as large as in the previous case.

The reversing of the field circuit however, causes severe sparking at the switch contacts as well as being likely to injure the field wire insulation.

A motor should never be reversed while running unless in the most necessary cases, and then not without inserting in the armature circuit the full resistance.

Reversing Connections. In Fig. 13 is shown a common form of reversing switch. The two metal bars *H* are pivoted one at *a*, and one at *b*. A strip *K* of insulating material joins the two bars. In the position shown the wire *A* is positive and *B* is negative. When the bars are switched to contacts *c* and *d* in the position indicated by the dotted lines, wire *B* then becomes positive and *A* negative.

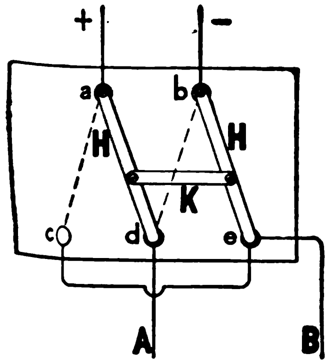

Fig. 13.

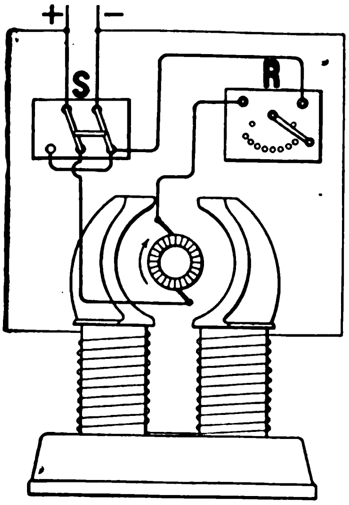

Fig. 14.

Fig. 14 shows the connections when a reversing switch *S* is inserted in the armature circuit of a shunt dynamo, the starting resistance being *R*. The reversing switch is sometimes combined with the starting resistance.

Maximum Output of Shunt Motor. We have seen that the maximum output of a motor when the only loss considered is that in the armature wires, is obtained when the armature current is $I = \frac{1}{2}\frac{E}{r}$; that is, when the strength of the current is one-half of that which would flow if the armature was restrained from rotating, the counter E. M. F. being equal to ½ E.

Since the stray power and field wire loss for a shunt motor on a constant potential circuit are approximately constant for any load, the loss in the armature winding is the only variable loss. For this reason Jacobi's law is also true for the commercial shunt motor.

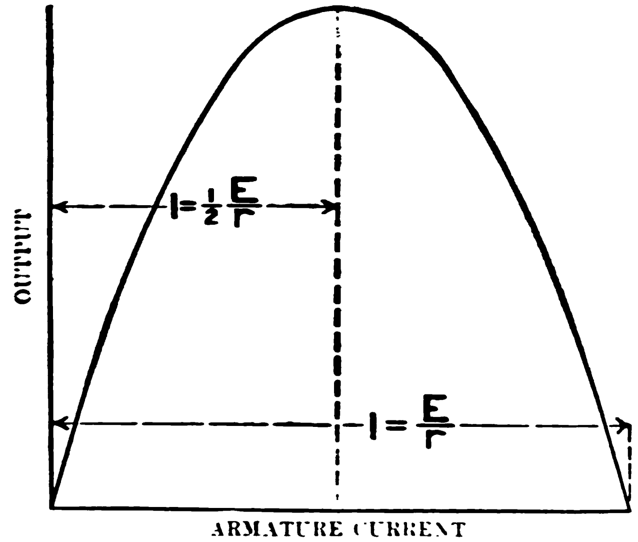

Fig. 15.

Fig. 15 shows the variation of the output with the armature current. At the beginning of the curve the current is zero, hence there could be no output. When the output has risen to its highest value, then $I = \frac{1}{2} \frac{E}{r}$ and $e = \frac{1}{2} E$. With a further increase in the current the output decreases until when $I = \frac{E}{r}$ the counter E. M. F. must be zero, that is; the motor is at rest and the output is zero.

Efficiency. Siemens' law of efficiency, $\left\{ \text{efficiency} = \frac{e}{E} \right\}$ is not closely followed by the commercial motor, since when the stray power and field wire loss is also taken into account, the efficiency will evidently be less than $\frac{e}{E}$.

It can be shown mathematically that the commercial efficiency shunt motor will be a maximum when the armature current uch a value that its square is equal to

$$\frac{\text{field wire loss} + \text{stray power loss,}}{\text{armature resistance}}$$

$$\text{or} \quad I^2 = \frac{i_1{}^2 r_1 + S.\,P.}{r}$$

re i_1 is the field current and r_1 the resistance of the field ling.

The variation of the commercial efficiency of a shunt motor

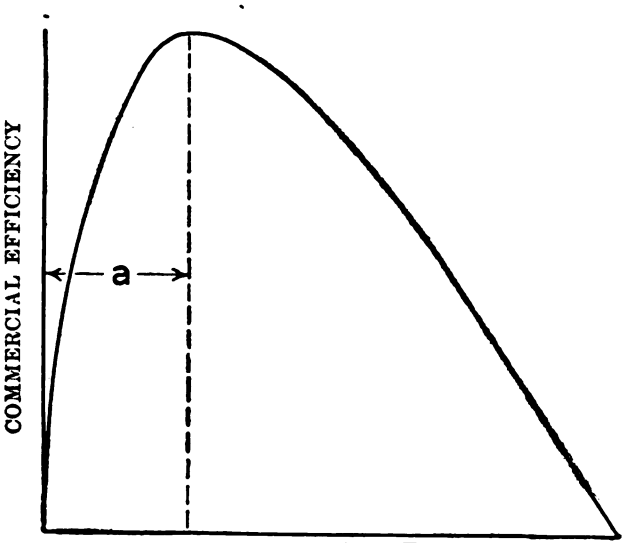

Fig. 16.

a change in the armature current is shown in Fig. 16. It is that the efficiency rapidly rises with an increase in the cur- to its maximum value, and decreases more slowly as the nt is further increased. When the efficiency is a maximum, alue of the current indicated by a in the figure is equal to

$$\sqrt{\frac{\text{field loss} + \text{stray power}}{\text{armature resistance}}}.$$

Advantage and Disadvantages of Shunt Motors. The great advantage of shunt motors is that their speed is practically constant.

The disadvantages are as follows:

1. The torque increases only in proportion to the armature current since the field strength is constant.

2. There is a high potential between the terminals of the field winding.

3. Opening the field circuit suddenly, causes a large spark and a high potential due to self-induction.

4. The many turns of fine wire of the field coils involve extra expense since fine wire costs more per pound than coarse, the labor of winding is considerable, and a large amount of insulation is necessary.

5. Where shunt motors are run intermittently it is customary to keep the field coils constantly charged, the motor being started and stopped by closing and opening the armature circuit through the resistance. Keeping the fields charged when the motor is not in use is of course a loss of energy.

Uses of Shunt Motors. A constant speed is of the greatest importance in some classes of work, and this advantage makes the use of shunt motors very extended.

Shunt motors are used in machine shops, factories, and to run printing presses, pumps, elevators, etc., or in general where good speed regulation is required.

SERIES MOTORS ON CONSTANT POTENTIAL CIRCUITS.

Torque. In the series motor the same current passes successively through the armature and field windings. We have seen that the torque depends upon the armature current and the field strength, or

$$T \text{ varies as } I f.$$

An increase in the current strength of a series motor greatly increases the torque because (*a*) the armature current is increased, and (*b*) the field strength is also increased by the larger field current. Hence in series motors the torque increases as the square of the current. Therefore on light loads the current is small and the

ןue is small, and on heavy loads the current being large, the ןue exerted is large. The torque increases as the square of current, however, only when the fields are below their point of ɹration. When near this point an increase in the current pro- :es but a slight increase in the field strength, and the torque l then vary as the current strength only.

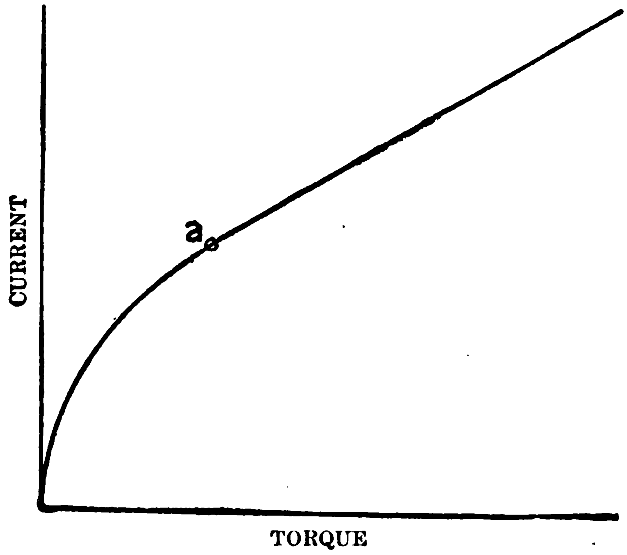

Fig. 17.

The curve in Fig. 17 shows the relation between the current :en by a series motor and the torque. Up to the point *a* the ɘ has a considerable curve because the fields being below satura- n, the torque increases as the square of the current. Beyond nt *a* the fields are saturated and the torque then varies as the rent only, the curve becoming a straight line.

Speed. In the case of shunt motors it was seen that the ed is nearly constant for all loads. In series motors the speed ies with the load. If part of the load is taken off of a series tor, the current becomes less, the fields are weakened, and this ıses a large increase in the speed. If the load is entirely ıoved the speed becomes dangerously high.

Fig. 18 shows the speed curve for a series motor. It is evident from this curve that with a small current, or light torque on the motor, the speed is very large; with a large current the speed is small.

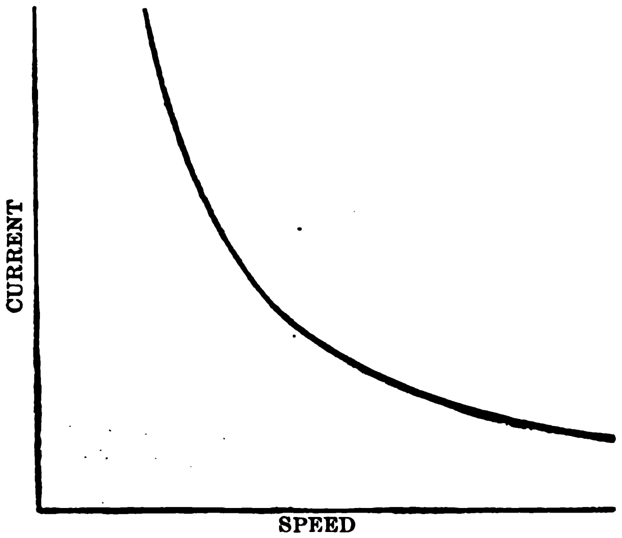

Fig. 18.

Speed Control of Series Motors. Series motors on constant potential circuits may have their speed controlled in a similar manner to that of shunt motors, there being some differences however, on account of the different field winding.

Variation of E. M. F. at the Brushes. This is the most common and most satisfactory method of controlling the speed. Fig. 19 illustrates this method, the resistance *R* being inserted to reduce the voltage available at the brushes, and consequently the speed. The current passes successively through the adjustable resistance *R*, the armature, and the field winding.

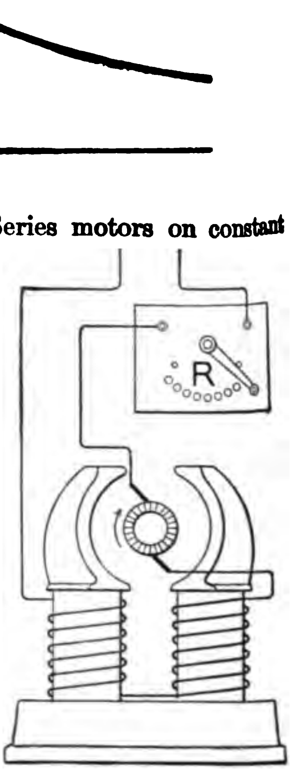

Fig. 19.

Variation of Field Strength. The field strength can be varied in several ways. If the field winding

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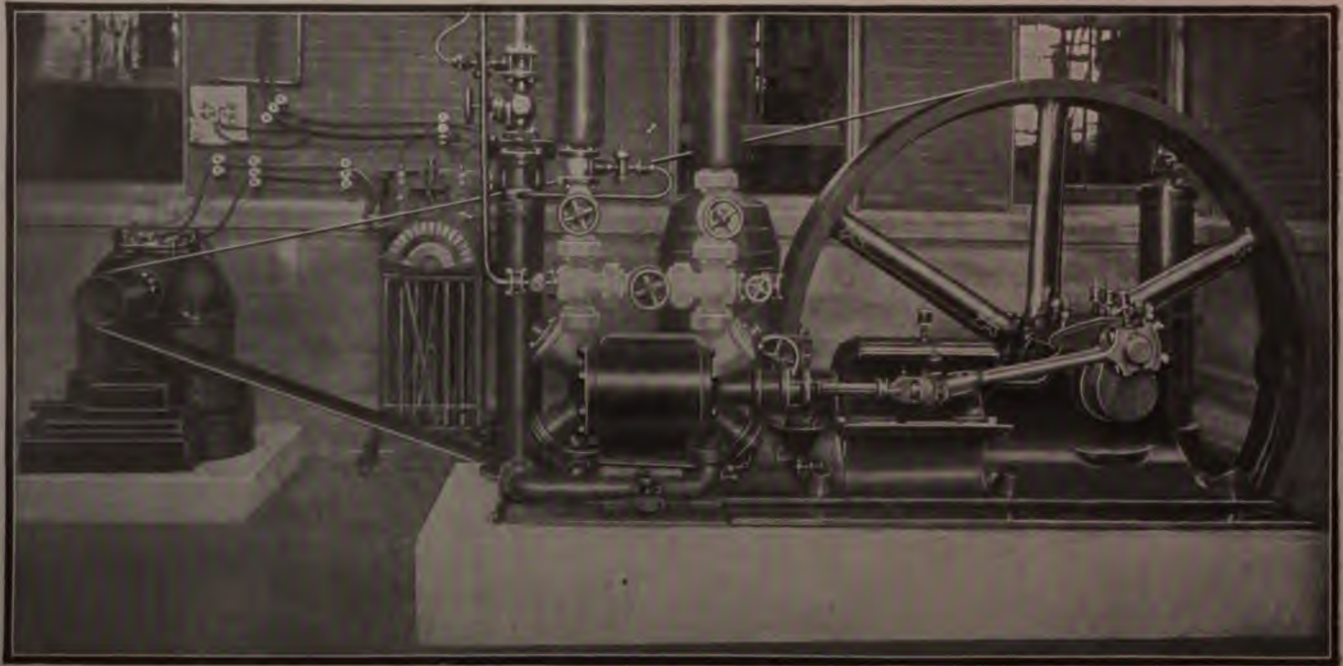

12-TON LINDE REFRIGERATING MACHINE.

Operated by an Electric Motor.

Fred W. Wolf Company.

is changed from a series coil to several coils in multiple the number of ampere-turns, and hence the magnetization will be reduced, causing the speed to be increased. Also cutting out turns or shunting a part of the field current through a by-path having an adjustable resistance will cause the speed to be increased. The latter method cannot be used for shunt motors, since the field winding is itself a shunt across the main circuit; but for series motors this method is a very useful one.

The resistance of the magnetic circuit may be varied as in shunt motors but this method is little used.

Other Methods. As in the case of shunt motors the speed of series motors may be varied by a change in the number of armature wires, as by coupling in series or multiple, and also by varying the position of the brushes. To obtain a very large range of speed there may be combinations of two or more methods.

Constant Speed. Nearly constant speed with varying load can be obtained with series motors by overwinding the field coils, that is, they may be wound so that the fields have their full strength when only one-half or even one-third of the normal current is passing. Hence with perhaps one-third load or more the fields will have a constant strength and the speed will be constant as in the case of the shunt motor. At full load the field current will be far greater than is necessary to saturate the magnets and consequently the efficiency is considerably lessened.

Starting. On starting, a rush of current tends to occur with this type of motor similar to that in case of the shunt motor; it is somewhat less however, because the field coils are in series with the armature and their resistance and self-induction reduce the excessive flow. A starting resistance is used as in the shunt motor, but can be considerably less.

Connections. These are very simple for a series motor and are indicated except the main switch and fuses, in Fig. 19; the same current passing successively through the starting resistance, armature and field winding.

Motors having more than two poles sometimes seem to have very complicated connections. Fig. 20 represents the connections for a four-pole series motor, and Fig. 21 for a four-pole shunt motor. By tracing out the connections the figures will be readily understood.

Reversing Series Motors. What has been said in regard to reversing shunt motors applies in general to series motors on constant potential circuits. Reversing while running is not so harmful to the latter as they are brought to rest sooner, since the excessive current passing through the field coils increases the field strength.

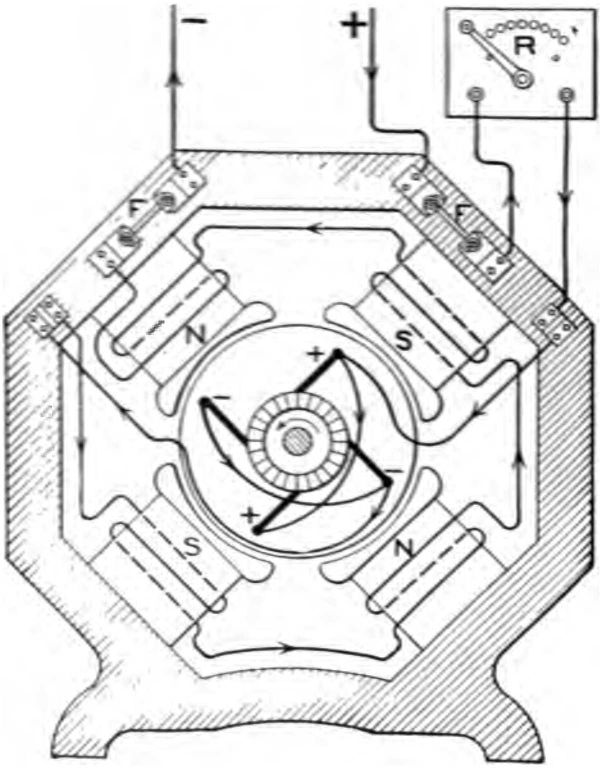

Fig. 20.

Advantages and Disadvantages of Series Motors. The advantages are:

1. The torque on overload is large; series motors are therefore well adapted for starting loads with great friction of repose.

2. The cost of the field coils is considerably less than in the case of shunt motors as the number of turns required is very much less.

3. The field coils and armature being in series one switch serves to cut out both at once.

The disadvantages are:

1. **The speed varies with the load.**

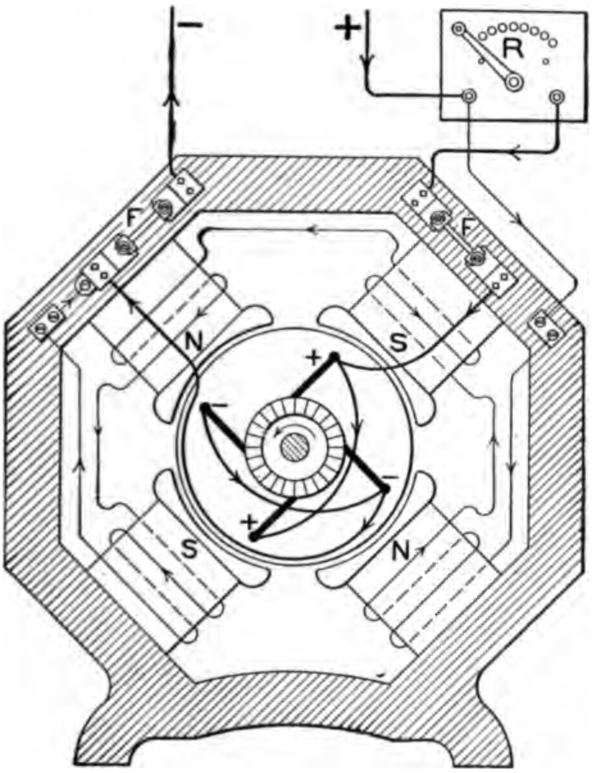

Fig. 21.

2. If the load is removed the speed becomes dangerously high and the motor may tear itself apart.

Uses of Series Motors. The most common use of this motor is in the electric railway where it is usually run on a 500 volt circuit. It is also used in operating hoists, mining machinery, and in general where the load cannot be entirely removed, where the starting torque required is large, and where a constant speed is not necessary.

COMPOUND MOTORS ON CONSTANT POTENTIAL CIRCUITS.

Compound Motors. The compound motor has two independent field windings; a shunt winding gives the main magnetization, and a series winding serves to regulate or to allow starting under heavy load.

Cumulative Compound Motor. This motor has the direction of the current in the series winding the same as that in the shunt winding and hence increases the field strength.

Such a motor has the advantage of a large torque on starting as in the case of a series motor, and an approximately constant speed as with the shunt motor. On starting the series coil is in the circuit, but is cut out when the motor has attained its full speed.

Use of Cumulative Compound Motor. The special use of this motor is where it is frequently stopped and started under a heavy load, and a nearly constant speed is desired.

Differential Compound Motor. The series winding in this motor has its current passing in an opposite direction to that in the shunt coil and consequently reduces the magnetization.

This motor gives a more constant speed than the simple shunt motor. We have seen that the speed of the shunt motor decreases *slightly* as the load increases; therefore if the field strength can be weakened with an increased load the speed can be kept up. The current in the series winding is greater the greater the load, hence the magnetization is reduced, and almost perfect speed regulation can be obtained.

It is necessary that the series coil should be inserted *after* starting the motor; otherwise its excessive current would weaken the fields so much that the starting torque would have hardly any value.

The differential motor has the serious disadvantage that with a large overload owing to the excessive current in the series coil, the field magnets may become demagnetized, and instead of the motor keeping up its speed it slows down or stops and is liable to burn out.

Use of Differential Compound Motor. Where a very constant speed is required this motor is used. The shunt motor, however, has a speed which is uniform enough for most purposes, and the differential motor is not much used now.

MOTORS ON CONSTANT CURRENT CIRCUITS.

Motors are now in use on constant current circuits to only a small extent. They cannot be made self-regulating, and therefore all have some form of mechanical governor to regulate the speed or torque. Another objection is the usually high potential of the circuits, this being a source of considerable danger.

Owing to the very general introduction of constant potential circuits, and the advantage of constant potential motors over motors which are not self-regulating, the latter have been largely superseded by the former.

Series Motors. The series wound motor is usually the type used on constant current circuits. As a constant current passes through the field and armature windings, the field strength and armature current will have a constant value and consequently the torque will be constant. Hence if the load is reduced the torque exerted remaining the same, the motor will speed up. If the load is entirely removed the speed becomes dangerously high, being much worse than when on a constant potential circuit for in the latter case the armature current is reduced as the speed increases. This increased speed can be prevented if the field is weakened, since the torque is then decreased, the armature current remaining the same.

The motor can be overloaded or held still without its being injured as the current is always the same, therefore no starting resistance is necessary and the throwing of a single switch starts or stops the motor.

Regulation. The usual method of changing the field strength to obtain constant speed is by cutting in or out turns of the field coils. The switch which does this is operated by some form of centrifugal governor, a slight increase of speed causing turns to be cut out and a slight decrease causing them to be inserted.

Another method is by rotation of the brushes. To reduce the field strength the brushes are rotated in a direction such that its magnetization will oppose that of the field magnets. To give a close regulation a comparatively large regulator is required.

MOTOR-GENERATORS.

Motor-generators, or dynamotors commonly called, are nearly synonymous terms applying to a combination of the *direct* *current* generator and motor, for the purpose of either increasing or decreasing the voltage of distribution.

The motor which drives the generator, is usually shunt-wound and is connected on constant potential mains.

The simplest case is where the motor is directly connected to the generator, the E. M. F. generated by the dynamo being available for any purpose. Such an arrangement allows a considerable variation of E. M. F. This is usually accomplished by inserting varying resistances in the field circuit of the dynamo; weakening the field, of course decreasing the volts generated.

Where the ratio of transformation of voltage is definite, one field may be common to both motor and dynamo. The armature has independent motor and generator windings which have separate commutators. As the field is common to both the only method of varying the E. M. F. of the dynamo is by inserting resistances in either armature circuit or by shifting the brushes.

CALCULATION OF ELECTRIC MOTORS.

As a direct current dynamo may be used either as a generator or motor, it is evident that the principles of construction and calculation of direct current generators apply equally well to that of motors. Hence for the calculation of an electric motor it is only necessary to determine the corresponding values for a generator at the required speed, and to then proceed as in the calculation of a generator.

The question arises as to what power must the motor be calculated for when considered as a generator. We have seen that the losses in a dynamo are the electrical and the stray power. In a generator the output is equal to the total electrical energy less the *electrical* losses. In a motor the output is equal to the total electrical energy, which is the input, less *all* the losses, that is, the electrical together with the stray power loss. Hence, in making the calculations of a motor we must allow for the stray power loss and figure a generator which at the given speed has an electrical activity in watts equal to

$$\frac{\text{motor output}}{\text{gross efficiency}}.$$

Small motors up to 5 horse-power have a gross efficiency of from 80% to 85%, that of motors from 5 to 20 horse-power ranges from 85% to 90%, from 20 to 300 horse-power ranges from 90% to 95%, and motors of more than 300 horse-power have a gross efficiency slightly above 95%.

The E. M. F. for which the generator is to be calculated is the *counter* E. M. F. of the motor, being the E. M. F. generated by the motor at the given speed. This from the motor equation is equal in the case of the shunt motor to

$$e = E - Ir,$$

where e is the counter E. M. F., E the applied E. M. F., I the armature current, and r the armature resistance.

For the series motor

$$e = E - I(r + r_1),$$

where r_1 is the resistance of the field winding.

As the value of the resistances and current are not known, e must be estimated from values obtained by experience. The percentage of the applied E. M. F. which is lost in the armature, or in the case of the series motor in the armature and field winding, varies greatly according to the size of the machine. For shunt motors the per cent of the applied E. M. F. which is lost in the armature, is approximately as follows:

Up to ¼ H. P.	15 %
Up to 1½ H. P.	10 %
Up to 3 H. P.	8 %
Up to 7 H. P.	6 %
Up to 15 H. P.	5 %
Up to 35 H. P.	4 %
Up to 75 H. P.	3½%
Up to 150 H. P.	3 %

For motors of a greater output than 150 H. P. the per cent lost may be a little less. In the case of series motors the volts lost in the armature and field winding may be found by taking about twice the above percentage.

Having determined the electrical activity and the voltage for which the motor is to be calculated. the current capacity is found by dividing the former by the latter.

Example.—It is desired to construct a shunt motor which is to have an output of 5 H. P. at a speed of 1,200 revolutions per minute, the motor to be run on a 110 volt circuit. Determine the values of the quantities to be used when calculated as a generator.

Solution.—For a 5 H. P. motor the gross efficiency is taken to be 85%. The watts generated by the armature are to be, therefore,

$$\frac{5 \times 746}{.85} = 4{,}400 \text{ watts (approx.)}.$$

Allowing 7% of the applied E. M. F. to be lost in the armature, the voltage to be generated, that is, the counter E. M. F., will be

$$110 \times .93 = 102 \text{ volts (approx.)}.$$

The current capacity will, therefore, be

$$\frac{4{,}400}{102} = 43 \text{ amperes (approx.)}.$$

Hence the armature is to be designed to generate a total E. M. F. of 102 volts, at a speed of 1,200 revolutions per minute, the current capacity to be 43 amperes.

Example.—Suppose we wish to design a series motor for a 220 volt circuit, the output to be 10 H. P. at 900 revolutions per minute. How is the machine to be designed?

Solution.—Supposing the gross efficiency to be 88% the number of watts to be generated is

$$\frac{10 \times 746}{.88} = 8{,}500 \text{ watts (approx.)}.$$

Allowing 12% of the applied E. M. F. to be lost in the armature and field winding the voltage to be generated is

$$220 \times .88 = 193 \text{ volts (approx.)}.$$

The current capacity is to be

$$\frac{8{,}500}{193} = 44 \text{ amperes (approx.)}.$$

Hence the armature is to be designed to generate a total E. M. F. of 193 volts at a speed of 900 revolutions per minute, the current capacity to be 44 amperes.

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bearings, or the tops of the field magnet, frame and bearings, or by moving the halves sideways if the frame is split vertically. The armature and field windings should be so designed and mounted that their removal for repairs is an easy matter.

Interchangeability. The machine selected should preferably be one of a regular and standard type, so that extra parts can be obtained without needless delay.

Regulation. Some form of regulating device should be provided by means of which the E. M. F. or current of a generator, or the speed, and in some cases the direction of rotation of a motor, can be readily and accurately controlled.

Form. The machine should be symmetrical, well-proportioned, compact and solid in form. The large and heavy portions should be placed as low as possible, to give greater stability.

Weight. It is a mistake to select a very light machine when it is for stationary use, since weight increases its strength, stability, and durability.

Capacity. This should be ample for the work to be done; in fact it is advisable to allow a margin for increase. The machine should be provided with the maker's name-plate, specifying the rated current, voltage, speed and capacity. The manufacturer should also guarantee the following: That the machine does not heat up in any part of its windings, to more than 50° C, after a run of six hours' duration, under rated load conditions;* also that it is able to carry a 25 per cent overload for two hours, and momentary overloads of 50 per cent, without excessive heating or sparking.

Cost. It is usually an error to select a generator or motor simply because it is cheap, since both the materials and workmanship required for the construction of a high-grade electrical machine are costly.

MECHANICAL CONDITIONS.

Location. The place chosen for the machine should be *dry, free from dust or grit, light, and well ventilated.* It must also be arranged so that there is room enough for the removal of the armature without shifting or turning the machine.

Foundations. It is of great importance to have the machine

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* NOTE. By resistance measurements.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

The object of this instruction paper is to set forth the most important features which must be considered in the actual handling and operation of electric generators and motors. The principles and general construction of direct-current (D. C.) and alternating-current (A. C.) generators and motors, are treated elsewhere.

The subject may be divided into three parts as follows:

A. The Selection, Erection, Connection, and Operation.
B. The Inspection and Testing.
C. The Troubles or "Diseases" and Remedies.

SELECTION OF A MACHINE.

The voltage, capacity, and type of machine are dependent upon the system to which it is to be connected, and the purpose for which it is to be utilized, but there are certain general features which should be considered in every case.

Construction. This should be of the most solid character and guaranteed first-class in every respect, including materials and workmanship.

Finish. A good finish is desirable, since it is likely to cause the attendant to take greater care of the equipment.

Simplicity. The machine should be as simple as possible in all its parts; peculiar or complicated features should be avoided, unless absolutely essential for the operation of the system.

Attention. The amount of attention required by the machine should be small. The number of screws or nuts should be reduced to a minimum, and they ought always to be provided with some locking device to prevent them from becoming loose. The brushes should be capable of being easily adjusted and self-feeding, so that they may "follow" or make up for any trifling eccentricity of the commutator. The bearings should be self-oiling, and in the smaller sizes self-aligning.

Handling. An eye-bolt or other means by which the machine can be easily lifted and moved is desirable. It ought to be possible to take out the armature conveniently by removing one of the bearings, or the tops of the field magnet, frame and bearings, or by moving the halves sideways if the frame is split vertically. The armature and field windings should be so designed and mounted that their removal for repairs is an easy matter.

Interchangeability. The machine selected should preferably be one of a regular and standard type, so that extra parts can be obtained without needless delay.

Regulation. Some form of regulating device should be provided by means of which the E. M. F. or current of a generator, or the speed, and in some cases the direction of rotation of a motor, can be readily and accurately controlled.

Form. The machine should be symmetrical, well-proportioned, compact and solid in form. The large and heavy portions should be placed as low as possible, to give greater stability.

Weight. It is a mistake to select a very light machine when it is for stationary use, since weight increases its strength, stability, and durability.

Capacity. This should be ample for the work to be done; in fact it is advisable to allow a margin for increase. The machine should be provided with the maker's name-plate, specifying the rated current, voltage, speed and capacity. The manufacturer should also guarantee the following: That the machine does not heat up in any part of its windings, to more than 50° C, after a run of six hours' duration, under rated load conditions;* also that it is able to carry a 25 per cent overload for two hours, and momentary overloads of 50 per cent, without excessive heating or sparking.

Cost. It is usually an error to select a generator or motor simply because it is cheap, since both the materials and workmanship required for the construction of a high-grade electrical machine are costly.

MECHANICAL CONDITIONS.

Location. The place chosen for the machine should be *dry, free from dust or grit, light, and well ventilated.* It must also be arranged so that there is room enough for the removal of the armature without shifting or turning the machine.

Foundations. It is of great importance to have the machine firmly placed upon a good and solid foundation; otherwise, no matter how well constructed and managed, the vibrations occurring on a poor foundation will produce sparking at the brushes, and its accompanying troubles.

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* NOTE. By resistance measurements.

It is also necessary, if the machine is belt-driven, to mount it upon rails or a sliding bed-plate provided with holding-down bolts and tightening screws for aligning and adjusting the belt while the machine is in operation. (See Fig. 1). The machinery foundations consist of a mass of stone, masonry, brickwork, or concrete, upon which the machinery is placed and usually held firmly in place by bolts passing entirely through the mass. These bolts are built into the foundations, the proper position for them being determined by a wooden template suspended above the foundation, as shown in Fig, 2. The bolts are preferably surrounded by iron pipe that fixes them longitudinally but allows a little side play which may be necessary to enable them to enter the bed-plate

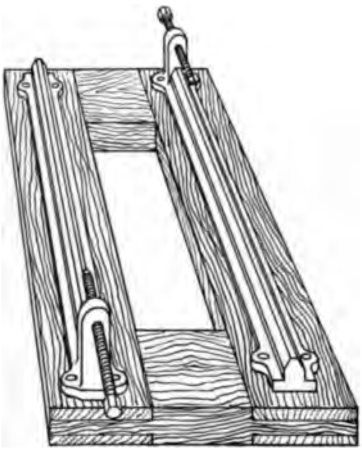


Fig. 1.

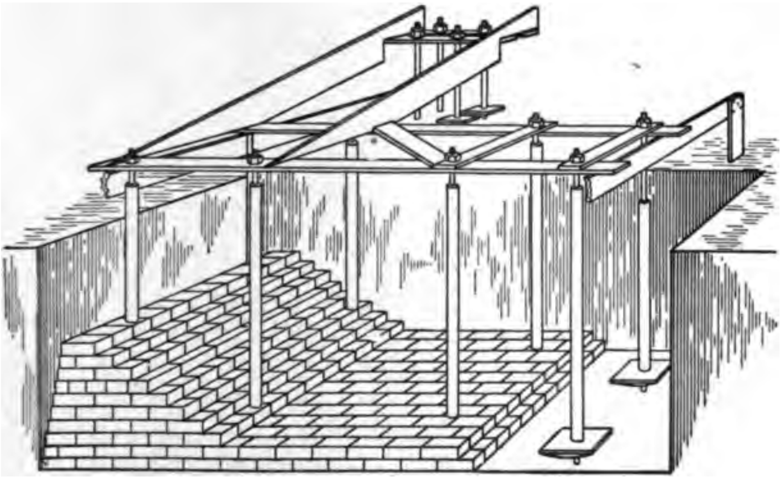


Fig. 2.

holes readily. The brickwork for machinery foundations should consist of hard burned bricks of first quality, *laid in good cement mortar.* Ordinary *lime mortar is entirely unfit* for the purpose, being likely to crumble away under the effect of the vibrations caused by the machinery. Brick or concrete foundations should be finished with a cap of bluestone or cement. This tends to hold the foundation together, and forms a level surface upon which to set the machinery. If the engine and generator are provided with a cast-iron sub-base, the capping may be dispensed with

Fixing the Machine. In fixing either direct-connected or belt-driven machines, first determine, with a long straight edge and spirit level, if the top of the foundation is level and true. If this is found to be the case, the holding-down bolts may be dropped into the holes in the foundation, if they are not already built in, and the machine carefully placed thereon, the ends of the bolts being passed through the holes in the bed-plate and secured by a few turns of the nuts. The machine should then, if belt-connected, be carefully aligned with the transmitting pulley or fly wheel. Particular attention should be paid to the alignment of the pulleys in order that the belt may run properly. If direct-connected, the dynamo bed-plate and armature shaft must be carefully aligned and adjusted with respect to the engine shaft, raising or lowering the bed-plates of the corresponding machines by means of thin cast-iron or other wedges; and the generator frame should also be adjusted to its proper height by means of thin strips of metal or fiber set between its supporting feet and the bed-plate. Having thus aligned and leveled the machine, it should next be grouted with thin cement. This is done by arranging a wall of mud or wooden battens around the bed-plates of the machines, and running in thin cement until the holding-down bolt holes are filled, and the cement has risen to the level of the under side of the bed-plate. When the cement has set, the wall may be removed and the nuts on the holding-down bolts drawn up. This firmly fixes the machine upon its foundation.

Mechanical Connections. Various means are employed to connect the engine or other prime mover with the generator, or the motor with the apparatus to be driven. The most important are as follows:

Direct Connection.
Belting.
Rope Driving.
Toothed Gearing.

Other apparatus, such as shafting, clutches, hangers and pulleys, are used in connection with the above means.

Direct Connection. This is the simplest, and for that reason the most desirable, means of connection, provided it can be carried out without involving sacrifices that offset its advantages. This method, also called direct coupling or direct driving, compels the engine and generator to run at the same speed, which gives rise to some difficulty, as the most desirable speeds of the two machines do not usually agree. The natural speed of a generator is high, while that of an engine is low; hence to obtain the same voltage from a direct-connected generator, more inductors are necessary, or the flux cut must be increased. Accordingly, the armature and frame of the direct-connected generator must be larger, thus making it a more expensive machine than the belt-driven.

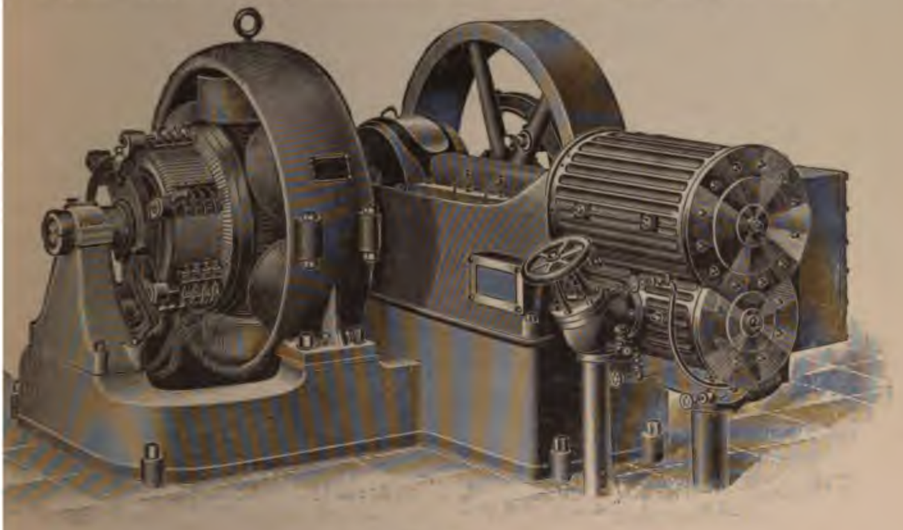


Fig. 3.

The direct connection of an engine and generator is accomplished in several ways; the simplest of which consists in mounting the armature of the generator directly on one end of the shaft of the engine. This may be accomplished in any one of several ways. Fig. 3 represents the three-bearing method. Two-and-four-bearing methods are also used. These secures the great advantages: that accurate alignment is readily obtained, and space occupied reduced to a minimum, and the mounting of the bearings on a common sub-base avoids trouble due to unequal settling.

Another form of direct coupling is that in which an engine and a generator, each complete in itself, and each having two bearings, are coupled together by some mechanical device, which may be either rigid or slightly elastic or adjustable. In the former case the two shafts are practically equivalent to a single one, which, while making it easy to remove either machine for repairs, is somewhat objectionable owing to the fact that it requires larger foundations, and introduces the difficulty of accurately aligning four bearings. The use of a flexible coupling avoids the necessity of perfect alignment, and also the serious trouble that might arise if the settling or the wear of the bearings should be uneven. There are various forms of flexible coupling. One of the forms manufactured by the Westinghouse Machine Company is shown in Fig. 4, the flexibility being provided by the springs which hold the two parts of the coupling together.

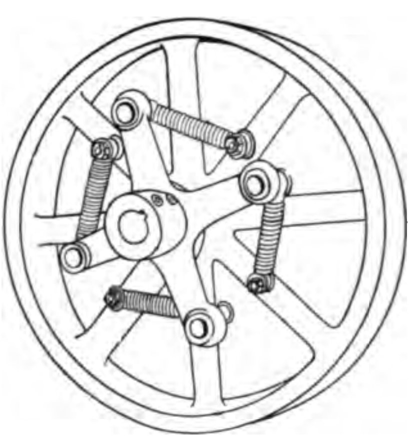
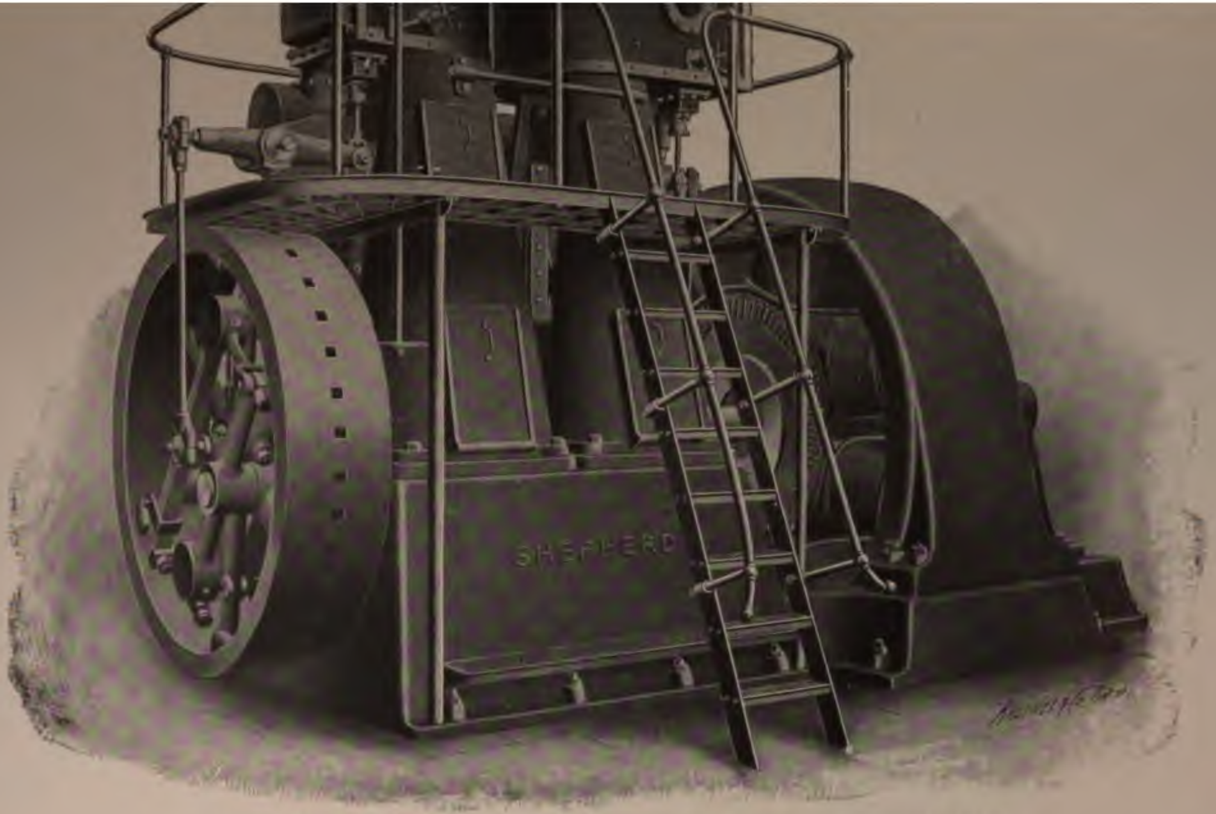


Fig. 4.

The direct coupling of generators with turbines can be carried out without departing from the natural speed of either machine, since the ordinary speed of a turbine agrees closely with the normal speed of a generator of the corresponding capacity.

The relative efficiency of direct coupling and belting depends greatly upon the conditions; but in general the former is more efficient at or near rated load, and the latter at light loads. *The simplicity, compactness, and positive and noiseless action of direct connection* have caused it to become the most approved method.

Belting. If the generator or motor is not directly connected,



VERTICAL CROSS-COMPOUND ENGINE DIRECT-CONNECTED TO 400 K.W. DYNAMO.

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one to the prime mover and the other to the apparatus to be driven, they are usually connected by some form of belting. The kind of belting selected depends greatly upon conditions of drive, distances, etc.; and it may be leather, rawhide, rubber, or rope. For ordinary short drives, leather is the most desirable, though, when the power to be transmitted is small, rawhide belts are also satisfactory, especially as the cost is less than for leather belts. For considerable distances, rope driving answers very well because it is so much lighter and cheaper than an equivalent leather belt, though grooved pulleys are required, making the total cost about the same. Rubber belts are used to advantage in driving generators from water turbines, where the belt might be exposed to moisture. Leather belting is usually the most reliable and satisfactory for general application, except for very short drives, where a form of chain belt works best. There are three thicknesses of leather belting—single, light-double, and double. For use in connection with generators, motors, or other high-speed machinery, the "light-double" belting is usually the best.

The exact amount of power that a given belt is capable of transmitting is not very definite. The ordinary rule is that "single" belt will transmit 1 horse-power for each inch of its width when traveling at a speed of 1,000 feet per minute. If the speed is greater or less, the power is proportionately increased or decreased. The statement of H. P. transmitted is based upon the condition that the belt is in contact with the transmitting pulley around one-half of its circumference, or 180°, which is usually the case. If the arc of contact is less than 180°, the power transmitted is less in the following proportion: An arc of 135° gives 84 per cent, while 90° contact gives only 64 per cent of the power derived from a belt contact of 180°. If on the other hand, the upper side sags downward, which is always desirable, the belt is in contact with more than half the circumference of the pulley; and thus the grip is considerably increased and more power can be transmitted. These facts make it very desirable to have the *loose side of the belt on top.* If the loose side is below, it sags away from the pulley and is also likely to strike the floor.

The complete expression for determining the width of a single belt required to transmit a given horse-power is as follows:

$$W = \frac{\text{H. P.} \times 1{,}000}{S \times C},$$

where W is the width of the belt in inches; H. P. the horse-power to be transmitted; S the speed of the belt in feet per minute, which is equal to the circumference of the driving pulley in feet multiplied by the number of revolutions per minute;* and C a factor dependent upon the arc of contact.

"Double" belting is expected to transmit one and one-half ($1\frac{1}{2}$), and "light-double" one and one-quarter ($1\frac{1}{4}$) times as much power as "single" belting of the same width. Belting formulas are only approximate, and should not be applied too rigidly, since the grip of the belt upon the pulley varies considerably under different conditions of tension, temperature and moisture. The smooth side of a belt should always be run against the pulley, as it transmits more power and is more durable. Belting used for electric machinery, being usually high-speed, should be made "endless" for permanent work, as this makes less noise; but it may be used with laced joints, temporarily. A spliced or "endless" joint is made as follows:—Both ends of the belt are pared down on one side (opposite) with a sharp knife, into the form of a long thin wedge, so that when laid together a long uniform joint is obtained of the *same thickness as the belt itself*. The parts are then firmly joined with cement and sometimes with rivets also. It may be necessary to splice or lace a belt while in position on the pulleys; and for this purpose some form of belt clamp (Fig. 5) should be employed.

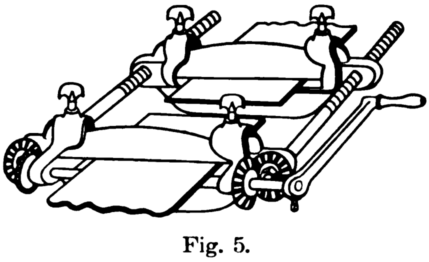

Fig. 5.

If a belt is ordered endless, or is spliced away from the pulleys, great care should be exercised in determining the exact length required. A string that will not stretch, or preferably a wire put around the pulleys in the position to be occupied by the belt, is the best way to avoid a mistake. In measuring for a belt, the generator or motor should be moved on its sliding base so as to make the distance between shaft centers a minimum, in order to allow for the stretch of the belt, which may be as much as ½ inch per foot of length.

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*Note. Belts slip or "creep" on the pulley about 2 per cent; hence, in determining the size of pulleys whose speed must be accurate, the calculated belt speed should be about 2 per cent too high.

The lacing of a belt is a very simple and common method of making a joint; but should not be permanently employed at high speeds for electric machinery belting, as it is liable to pound on the pulleys, producing noise, vibration and sparking; and in the case of generators it is also likely to cause flickering in the lamps. In lacing belts, the ends should be cut *perfectly square, and there should be as many stitches of the lace slanting to the left as there are to the right;* otherwise the ends of the belt will shift sidewise owing to the unequal strain, and the projecting corners may strike or catch in the clothing of persons. A good way to accomplish this is shown in Fig. 6. The various holes should be made with a circular punch, the nearest one being about ¾ inch from the side, and the line through the center of the row of holes about 1 inch from the end of the belt. In large belts these distances should be a little greater. A regular belt lacing of strong pliable leather or a special wire is used. The lacing is doubled to find its middle; and the two ends are passed through the two holes marked "*1*" and "*1a*," precisely as in lacing a shoe. The two ends are then passed successively through the two series of holes, in the order in which they are numbered, *2*, *3*, *4*, etc., and *2a*, *3a*, *4a*, etc., finishing at *13* and *13a*, which are additional holes for securing the ends of the lace. The great advantage of this method of lacing is that the lace lies on the pulley side perfectly parallel to the direction of motion.

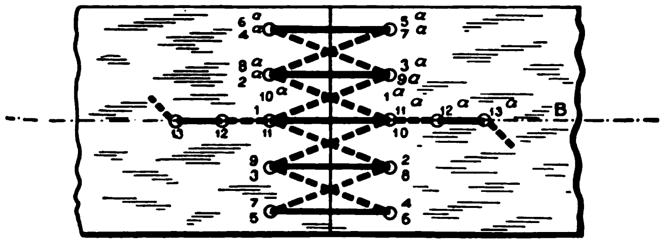

Fig. 6.

Perforated belts are often employed for the reason that a film of air is likely to be imprisoned between the belt and the pulley, thus preventing a good grip. Hence small perforations are sometimes made in the belt, especially for high-speed operation (3,000-5,000 feet per minute), to allow the air to escape; and since these are in the form of narrow slits, with their greatest dimension in the direction of motion, they do not materially reduce the strength of the belt.

Arrangement and Care of Belting. It is very desirable, for satisfactory running, that belts should be reasonably long and nearly horizontal. The distance between the centers of two belt-connected pulleys should be not less than 3 times the diameter of the larger pulley. The belt should be just tight enough to avoid slipping, without straining the shaft or bearings. The two shafts which are to be belt-connected must be perfectly parallel, and the centers of the face of the driving and driven pulleys must be exactly opposite to each other, in a straight line perpendicular to the axis of the shafts. The machines should then be turned over slowly with the belt on, to see if the latter tends to run to one side of the pulley, which would show that it is not yet properly "lined up," in which case one or both machines should be slightly shifted, until the belt runs properly. If possible, the machine and belt should be set and adjusted so as to cause the armature to move back and forth in the bearings while running, on account of the side motion of the belt, and thus make the commutator wear more smoothly, and distribute the oil in the bearings.

It is always desirable to have belts as pliable as possible; hence the occasional use of a good belt dressing—as neatsfoot oil, etc.—is recommended. Rosin and other sticky substances are sometimes applied to increase the adhesion; but this is a practice allowable only in an emergency, as it may destroy the belt surface.

In places where the belting is very much exposed, and liable to catch in the clothing of any person, it is advisable to surround it by a railing or box.

Rope Driving possesses advantages over ordinary belting in some cases. The rope runs in V-shaped grooves in the peripheries of the pulleys, and thereby obtains a great grip by a sort of wedging action. The kinds of rope ordinarily employed for this purpose are cotton, hemp, rawhide and wire. The general advantages are:

1. Economy in cost.

2. Large amount of power that can be transmitted with a given diameter and width of pulley, on account of the grip obtained.

3. It is almost noiseless.

4. Ropes, on account of their lightness, can be used to transmit power over greater distances than are possible with any other form of belting; and also for very short distances on account of the wedging action. Manila rope is generally used in the United States, being of three strands, hawser laid, and may be from ½ inch to 2 inches in diameter. The breaking strength varies from 7,000 to 12,000 pounds per square inch of cross-section. It has been found that the best results are obtained when the tension in the driving side of the rope is only 3 to 4 per cent of the breaking strength.

The diameter of a single rope necessary to transmit a required H. P. is given by the formula:

$$D^2 = \frac{825 \text{ H.P.}}{V\left(200 - \frac{V^2}{1{,}072}\right)},$$

in which H. P. = horse-power transmitted;
V = velocity of rope in feet per second;
D = diameter of rope in inches.

The maximum power is obtained at a speed of about 84 feet per second. With higher speeds the centrifugal force becomes so great that the power transmitted decreases rapidly, and at about 142 feet per second it counteracts the whole allowable tension (200 D^2 pounds) and no power is transmitted.

Arrangement of Rope Belting. There are two methods of arranging rope transmission: one consists in using several separate belts; and the other employs a single endless rope which passes spirally around the pulley several times and is brought back to the first groove by a slanting idle pulley, and therefore is called the "wound" system. The separate ropes do not require the carrying-over pulley, and if one rope breaks, those remaining are sufficient to transmit the power temporarily; whereas an accident with the single-rope system entirely interrupts the service. In the "multi-rope" system it is practically impossible to make and maintain the belts of exactly equal length, hence the tensions on the various ropes differ, and they hang at different heights on the slack side, producing an awkward appearance.

Toothed Gearing possesses the decided advantages of positive action and the ability to give large ratios of speed and small side pressure on the bearings. Nevertheless it is seldom employed for driving generators. As the most extensive applications of gearing for electrical purposes are in connection with railway motors, it will be taken up under that heading.

SHAFTING.

An intermediate or counter shaft is not desirable since it increases the complication and frictional losses of the system; but it is often necessary in the generation or application of electric power, either to obtain a greater multiplication of speed than is possible by belting directly, or to enable a single engine or motor to drive a greater number of machines.

The two important kinds of shaftings are "cold-rolled" and "turned." The former is rolled to the exact size and requires no further treatment. It has the advantage of a smooth, hard surface, but it is difficult to make perfectly true and straight. Turned-steel shafting is most commonly employed, and has the advantage that shoulders, journals, or other variations in size can be easily made on it. The following table gives the ordinary data for shafting:

TABLE I.

Shafting.

Diameter in inches.	Weight lbs. per ft.	Allowable H. P. transmitted at 100 r. p. m.	Width of key seat in inches.
$1\frac{7}{16}$	5.5	4.3	$\frac{3}{8}$
$1\frac{15}{16}$	10.	10.	$\frac{1}{2}$
$2\frac{7}{16}$	15.8	20.	$\frac{3}{4}$
$2\frac{15}{16}$	23.	34.	$\frac{3}{4}$
$3\frac{7}{16}$	31.5	54.	$\frac{7}{8}$
$3\frac{15}{16}$	41.	80.	1
$4\frac{7}{8}$	62.8	156.	1
$5\frac{7}{8}$	91.1	270.	1

With speeds greater than 100 r. p. m., the allowable H. P. varies directly in proportion to the speed employed.

ASSEMBLING OF THE MACHINE.

In unpacking and putting the machine together, great care should be used to avoid the least injury to any part, to clean scrupulously each part, and to put the parts together in exactly the right way. This care is particularly important with regard to the shaft, bearings, magnetic joints, and electrical connections, from which every particle of grit, dust, metal chips, waste, etc., should be removed. It is advisable to study carefully the blue prints or instruction matter usually sent with each machine, before attempting to put it together. The armature must be handled with great care in order not to injure the wires and their insulation as well as the commutator and shaft. The armature should be handled as far as possible by the shaft, and when it must be placed on the ground a pad of cloth or layer of boards should be interposed. A convenient form of sling for handling armatures with their shafts in position is shown in Fig. 7. The bearings should be carefully cleaned, set in exactly the right positions, and firmly secured. The tops should be left loose for a short time, so that the tendency to heat up at the first run may be decreased; and after that they

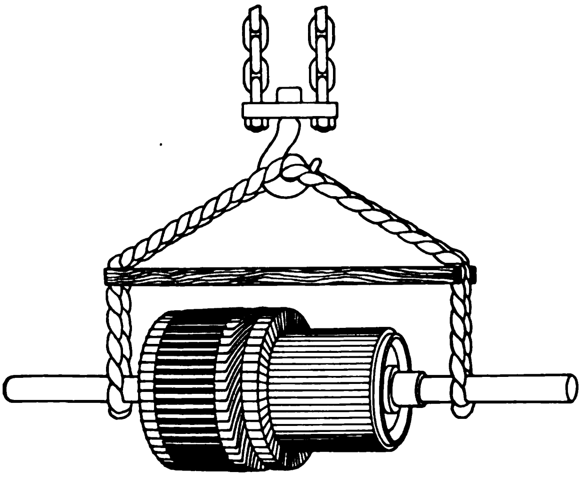

Fig. 7.

should be drawn up tight. The field frame should be set so that the air gap is the same for all pole pieces, as otherwise the machine will be magnetically unbalanced and tend to spark badly.

The adjustment of the brushes, etc., should preferably be left until the machine is electrically connected and ready to receive its trial run.

METHODS OF WIRING.

Before laying the wires, the circuits should be carefully mapped out and the work so planned as to secure the simplest arrangement. The wiring should then be installed neatly and in accordance with the rules of the National Board of Fire Underwriters and of the local department having supervision. Otherwise unnecessary trouble, delay and expense may be incurred.

The wire may be installed in one of two general methods, *viz.:*

- Exposed on
  - Cleats.
  - Knobs.
  - Bushings.
- Concealed in
  - Wooden moulding.
  - Iron conduit.
  - Terra cotta conduit.

The wire should preferably be either rubber-covered or made up in the form of lead cables. Exposed wires possess the advantages of cheapness, as well as accessibility for inspection and repair; and any short circuit or ground is readily seen and removed, whereas it might cause great uncertainty and delay when the wires are concealed.

Concealed conductors, especially where they are placed under the floor, have the great advantage over exposed wiring, in that they are entirely out of the way. This is especially important in large installations, where overhead traveling cranes are almost a necessity.

When alternating-current conductors are enclosed in iron conduits, both wires of each phase, or all the wires, must be run in the same duct, otherwise the inductance would be excessive.

All conductors, including those connecting the machine with the switchboard, as well as the bus bars on the latter, should be of ample size to be free from overheating and excessive loss of voltage. The drop between the generator and switchboard should not exceed ½ per cent at full load, because it interferes with proper ulation and adds to the less easily avoided drop on the distribu- n system.

The safe carrying capacities of copper conductors as recom- nded by the Board of Fire Underwriters, are given in the fol- ing table:

TABLE II.

Safe Carrying Capacities of Copper Wires.

B. & S. G.	Rubber Insulation. Amperes.	Other Insulations. Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
Circular Mils.			
200,000	200	300	
300,000	270	400	
400,000	330	500	
500,000	390	590	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
1,700,000	930	1,490	
1,800,000	970	1,550	
1,900,000	1,010	1,610	
2,000,000	1,050	1,670	

The lower limit is specified for rubber-covered wires to prevent gradual erioration of the high insulations by the heat of the wires, but not from r of igniting the insulation. The question of drop is not taken into con eration in the above tables.

The carrying capacity of Nos. 16 and 18, B & S. gage wire is given, but smaller than No. 14 is to be used.

The safe carrying capacity of insulated aluminum wire is 84 per cent of that given for copper wires of corresponding size and insulation.

Switches are devices for closing and opening the various circuits or branches of an electrical distribution system. A knife switch should always be employed when the capacity of the circuit to be controlled exceeds 10 amperes. It may be single-, double-, or triple-pole; single- or double-throw; and with or without fuses as desired. If the rated capacity of a switch exeeeds 25 amperes, its terminals must be provided with lugs into which the ends of the conducting wires should be soldered. The principal parts of a knife switch (Fig. 8) are the *base* (*a*), which must consist of a non-combustible, non-absorptive insulating material; the *hinges* (*b*), which carry the *blades* (*c*); the contact *jaws* or *clips* (*d*); the insulating *cross-bar* (*e*); and the *handle* (*f*). The hinges, blades and jaws should be made of pure copper, of sufficient cross-section to insure mechanical stiffness and proper carrying capacity, and their contact surfaces must not be less than 1 square inch per 75 amperes of the rating. The hinges and contact jaws must be springy enough to insure good contact with the blades. The blades and jaws must be so shaped that they open along their entire length simultaneously; otherwise the arc which is formed upon opening a loaded circuit, will burn off the last points of contact. In fact this arc, when produced by a heavy current, is very difficult to control; and switches should never be opened on heavily-loaded circuits except in an emergency. In practice, however, some form of electro-magnetic circuit-breaker is employed for the purpose, and may be operated automatically with overload, or by hand at any time.

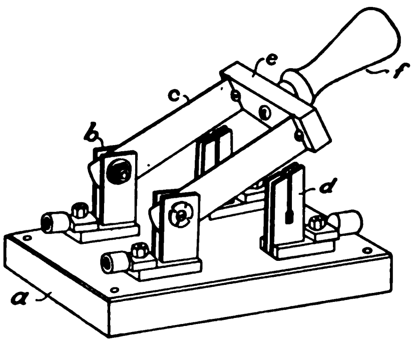

Fig. 8.

Knife switches should be so placed that *gravity tends to open* rather than to close them. They should always be located in dry, accessible places and grouped as far as possible If located in exposed positions they should be enclosed in slate or equivalently lined cabinets. The distances between the parts of opposite polarity, in an approved knife switch, must never be less than the values given in the following table:

TABLE III.

Switch Data.

125 VOLTS OR LESS:		Minimum Separation of Nearest Metal Parts of Opposite Polarity.	Minimum Break-Distance.
For Switchboards and Panel Boards—			
10	amperes or less	¾ inch	½ inch.
11-25	“	1 “	¾ “
26-50	“	1¼ “	1 “
For Individual Switches—			
10	amperes or less	1 inch	¾ inch.
11- 35	“	1¼ “	1 “
36- 100	“	1½ “	1¼ “
101- 300	“	2¼ “	2 “
301- 600	“	2¾ “	2½ “
601-1,000	“	3 “	2¾ “
126 TO 250 VOLTS:			
For all Switches—			
10	amperes or less	1½ inch	1¼ inch.
11- 35	“	1¾ “	1½ “
36- 100	“	2¼ “	2 “
101- 300	“	2½ “	2¼ “
301- 600	“	2¾ “	2½ “
601-1,000	“	3 “	2¾ “

On switchboards, the above spacings for 250 volts direct current are also approved for 440 volts alternating current. Switches on switchboards with these spacings intended for use on alternating-current systems with voltages above 250, must be stamped with the voltage for which they are designed, followed by the letters “A. C.”

251 TO 600 VOLTS:			
For all Switches—			
10	amperes or less	3½ inch	3 inch.
11- 35	“	4 “	3½ “
36-100	“	4½ “	4 “

Auxiliary breaks or the equivalent are recommended for switches designed for over 300 volts and less than 100 amperes, and will be required on switches designed *for use in breaking currents* greater than 100 amperes at a pressure of more than 300 volts.

For three-wire systems switches must have the break-distance required for circuits of the potential of the outside wires.

Safety Fuses and Cut-outs. Almost all electrical circuits, except those for constant-current arc lighting, are protected from abnormal increase of current by safety fuses. These consist of wires or strips of metal introduced into the circuit, and so designed in cross-section and resistance that they will melt and open the circuit in case of excessive current, before the rest of the system becomes unduly heated.

The requirements for effective safety fuses may be stated as follows:

1. They should melt at a definite current.
2. They should not change in this respect by the effect of time, nor by heating or other action of the current, nor, in fact, under any reasonable conditions.
3. They should act promptly.
4. They should give firm and lasting contacts with the terminals to which they are attached.

These fuses are of two general types:

(*a*) Open or link fuses.
(*b*) Enclosed or cartridge fuses.

The open or link fuses (Fig. 9) consist of strips of fusible alloy provided with copper terminals. Each size is designed to carry a certain normal current, but will melt and open the circuit when the current exceeds that rating by 25 per cent. When a link fuse "blows" as a result of overloading, the rupture is accompanied by a flash, and by spattering of the fused material. With large currents this phenomenon is a source of danger, and the use of enclosed fuses is accordingly recommended whenever the rating of the fuse exceeds 25 amperes.

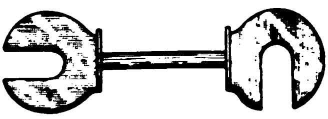
Fig. 9.

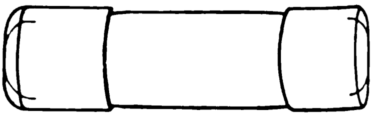
Fig. 10.

Enclosed fuses (Fig. 10) have a casing around the fusible material, which prevents the dangerous spattering and which also smothers the arc that tends to form whenever a fuse blows.

Fuses should always be employed when the size of the wire changes, or where connections between any electrical apparatus and the conductors are made. They must be mounted on slate, marble, or porcelain bases; and all metallic fittings employed in making electrical contacts must have sufficient cross-section to insure mechanical stiffness and carrying capacity.

Electro-magnetic Circuit-Breakers or **Limit Switches** are frequently used in place of fuses to protect electrical circuits. Their general construction and application are indicated in Fig. 11. The current is led through a helix A the electro-magnetic action of which, when the current reaches a predetermined limit, automatically releases the blades from contact with the jaws and thus opens the circuit. The final break occurs at carbon tips, thus preventing destructive arcing at the copper contacts. Circuit-breakers possess the following advantages over fuses:

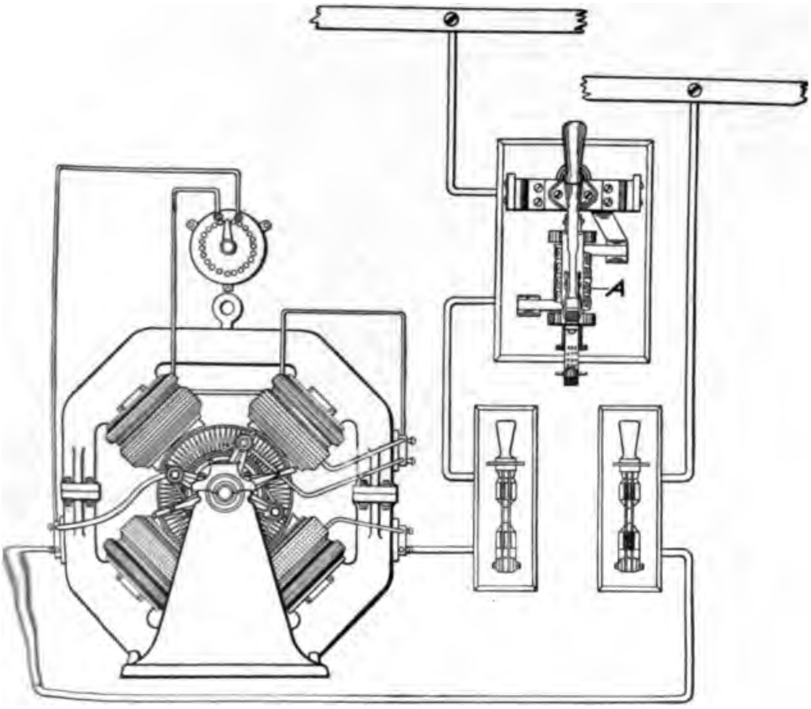

Fig. 11.

1. They can be employed as switches if desired.
2. They can easily be reset and thus put into condition for acting again.

3. Their range can be easily varied within considerable limits.
4. They can also be made to operate "tell tales" whenever the circuit they control is opened.

On account of these general advantages, their use is advisable on switchboards of systems that are liable to frequent overloads. The circuits, however, should, as a rule, be provided also with fuses, since it is possible that the circuit-breaker may fail to open, owing to corrosion or other cause.

Starting-Boxes should always be furnished with D. C. motors, for the following reason: If the line voltage should be applied directly to the terminals of the armature while it is standing still, a very excessive current would flow, since the resistance is low and no C. E. M. F. exists. Hence, to prevent injury to the winding, a resistance is inserted between one supply terminal and the armature in order to reduce the electromotive force at the motor terminals while it is speeding up, the resistance being gradually reduced until completely removed when rated speed is reached. All motor starting-boxes must also be provided with a **no-voltage release.** This consists of an electro-magnet in series with the shunt-field circuit, which holds the rheostat arm in the operating position as long as current flows through the shunt field from the line. If the line switch be opened or the shunt-field circuit accidentally broken, the device becomes demagnetized and releases the arm, which returns to its starting position (all resistance in circuit) by the action of a spring or of gravity. The starting-boxes of larger motors are also frequently equipped with **overload releases.** These, practically, are electro-magnetic circuit-breakers which open the supply lines if the motor becomes greatly overloaded. The general arrangement of switches, cut-outs and starting-boxes should be in accordance with the following extract from the Rules of the National Board of Fire Underwriters:

"Each motor and starting-box must be protected by a cut-out and controlled by a switch, said switch plainly indicating whether 'on' or 'off.' The switch and rheostat must be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

"Where the circuit-breaking device on the motor-starting rheostat disconnects all wires of the circuit, this switch may be omitted.

"Overload-release devices on motor-starting rheostats will not be considered to take the place of the cut-out required if they are inoperative during the starting of the motor.

"The switch is necessary for entirely disconnecting the motor when not in use; and the cut-out, to protect the motor from excessive currents due to accidents or careless handling when starting. An automatic circuit-breaker disconnecting all wires of the circuit, may, however, serve as both switch and cut-out."

The **Various Kinds of Circuit** on which motors and generators are commonly used, and the best type of machine in each case, are as follows :

TABLE IV.

Types of Machine for Various Kinds of Circuits.

DIRECT-CURRENT, CONSTANT-POTENTIAL.

Circuits on which potential or voltage is kept constant; machines, lamps, etc., being run in parallel.

Currents intended for—	Potential.	Generator should be—	Motor should be—
Electro-metallurgy.	1 to 150 volts	Shunt-wound.	Not used.
Incandescent lighting.	110 to 125 volts (2-wire sys.) 220 to 250 volts (2-or 3-wire sys.)	Shunt- or compound-wound.	Shunt-wound for constant speed. Sometimes series- or compound-wound for variable speed.
Electric railway Electric power.	500 to 660 volts	Compound-wound.	Series-wound for railway. Shunt-wound for stationary.

DIRECT, CONSTANT-CURRENT.

Circuits on which current or amperes are kept constant; machines, lamps, etc., being run in series.

Circuits intended for—	Current in Amperes.	Generator should be—	Motor.
Arc lighting.	6.8 or 9.6	Series-wound with current regulator.	No longer used.

ALTERNATING-CURRENT, POLYPHASE.

Constant-potential, two- or three-phase currents.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor is—
Power transmission.	On the line, 5,000 to 60,000.	In the machines, varying 500 to 12,000	Separately excited.	Synchronous or Induction.

ALTERNATING-CURRENT, SINGLE-PHASE.

Almost always constant-potential.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor should be—
Incandescent lighting. Arc lighting. Sometimes constant-current. Electric power.	Primary, 1,000 or more,	Secondary, 104 or 208.	Separately excited. Also sometimes composite-wound.	Synchronous. Induction. Series. Repulsion.

Diagrams of Connections are given for each important case, to show what is actually required. These merely represent the path of the currents in the simplest way, the important thing being to have these paths right, and to know which parts or wires are to be connected. The case of plants operating with only a single generator will be first considered, and then the parallel or series operation of several machines described.

Shunt Dynamo, Supplying Constant-Potential Circuit. A machine of the above type is represented in Fig. 12, with the necessary connections. The brushes are connected to the two conductors forming the main circuit; also to the field-magnet coils *Sh* through a resistance-box R, to regulate the strength of current and therefore the magnetism in the field. A voltmeter is also connected to the two brushes or main conductors, to measure the voltage or electrical pressure between them. One of the main conductors is connected through an ammeter A, which measures the total current on the main circuit. The lamps L, or motors M, are connected in parallel between the main conductors or between branches from them. This represents the ordinary low-tension system for electric light and power distribution from isolated plants or central stations.

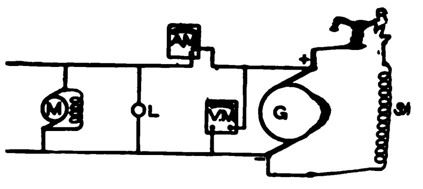

Fig. 12.

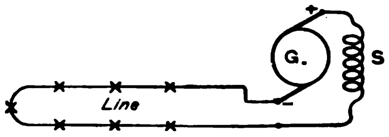

Fig. 13.

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Series Dynamo Supplying Constant-Current Circuits. The connections in this case are extremely simple, the armature, field coils, ammeter, main circuit, and lamps all being connected in one series (Fig. 13), the current being kept constant. This system is used for series D. C. arc lighting.

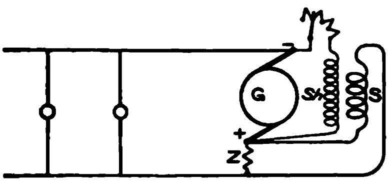


Fig. 14.

Compound Direct-Current Dynamo. This machine is a combination of the two foregoing types as regards field winding; but its load of lamps and motors are connected in parallel, as shown in Fig. 14. The resistance Z is known as the "series" shunt, and is for adjusting the percentage of compounding. The greater the resistance of Z, the greater the current passing through the series field, and the greater the compounding. This type of machine is most extensively employed in electric railway and in isolated plant work.

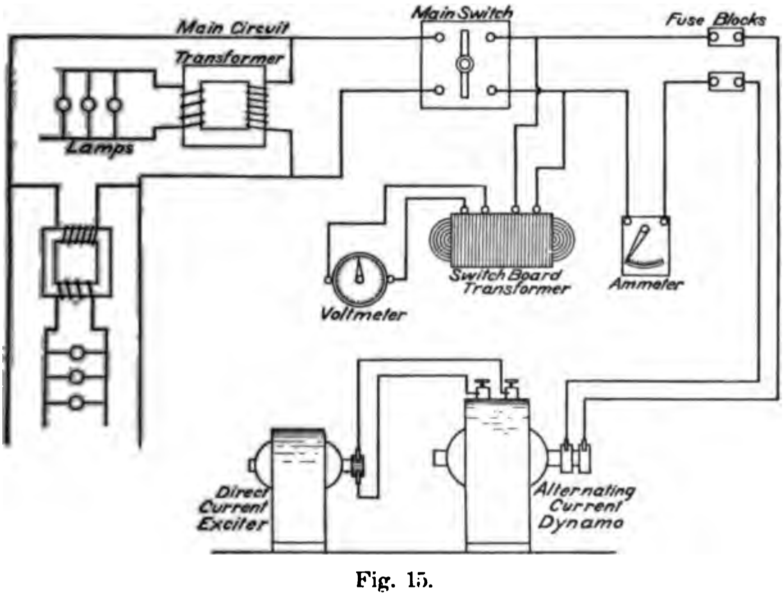


Fig. 15.

Alternating-Current Plants. The connections for a single-phase installation are shown in Fig. 15, in which the names of the different parts are given. This system is extensively used for lighting over considerable distances, and is very well adapted to street railway work. The wiring of a two-phase system is essentially double that given above, and can be treated as a system consisting of two single-phase circuits.

The wiring of a three-phase system is as shown in Figs. 16*a* and 16*b*, the former being known as the "Y" system or "Star" system, and the latter as the "Delta" Δ system or "Mesh" system. When the Y system is required for both lighting and power, it is arranged as shown in Fig. 16*a*.

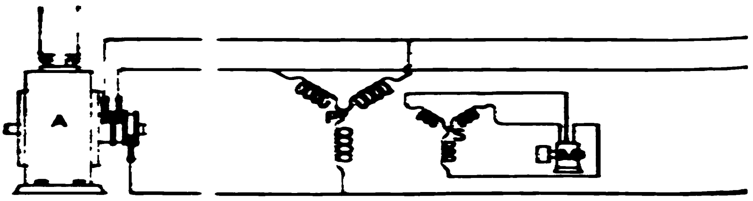


Fig. 16*a*.

The **Direction of Rotation** of the various machines is sometimes a matter of doubt or trouble. Almost any generator or motor is intended to be run in a certain direction; that is, it is called "right-handed" or "left-handed" according to whether the armature does or does not revolve like the hands of a clock, when looked at from the pulley end. Generators and motors are usually

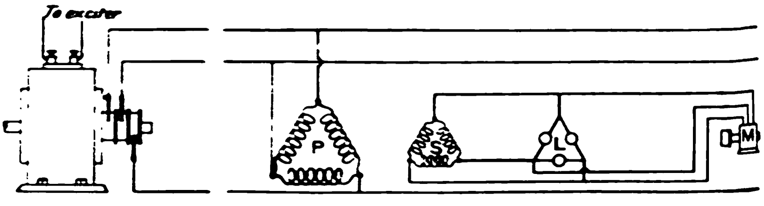


Fig. 16*b*.

designed to be right-handed, but the manufacturer will make them left-handed if specially ordered. This may be required because the other pulley to which the machine is to be connected happens to revolve left-handed; or it may be necessary in order to bring the loose side of the belt on top, or to permit the machine to occupy a certain position where space is limited.

To reverse the direction of rotation of an ordinary shunt (or series) direct-current bipolar motor, the brushes may simply be reversed as indicated in Fig. 17, without changing any connection. This changes the point of contact of each brush tip 180°.

If the machine is multipolar, a similar change must be made, amounting to 90° in a four-pole, 45° in an eight-pole machine, etc.

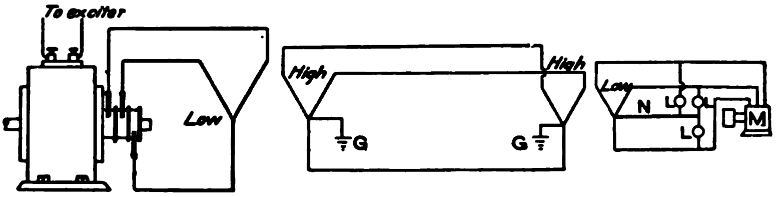


Fig. 16c

The direction of the current and the polarity of the field magnets remain the same as before; all that is changed is the direction of rotation and the position of the brushes. This applies to any machine (either motor or generator) except arc dynamos and one or two other peculiar machines, which require to be run in a certain direction to suit the regulating apparatus.

A separately excited alternating-current generator can be reversed in direction of rotation without changing any connection. A self-exciting or compound-wound alternator requires the brushes that supply the direct current to the field to be reversed upon the

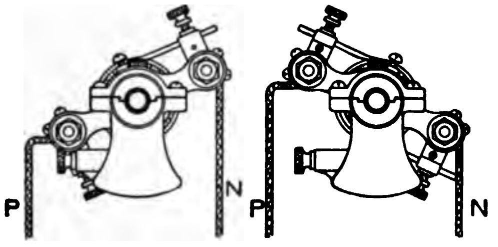


Fig. 17.

commutator, and their tips moved through an angle as above stated, if the rotation is to be reversed.

In any case, copper brushes (unless they be gauze brushes pressing radially upon the commutator) should point in the direction of rotation; but carbon brushes, particularly if they are perpendicular to the surface of the commutator, allow the armature to be revolved in either direction.

If the direction of the current from a generator is opposite to that desired, the two wires leading from it should exchange places in the terminals. If this is not desirable, the residual magnetism may be reversed by passing through the field winding a current opposite in direction to the original current.

Changing the direction of the current by reversing the main wires or otherwise, does not reverse the direction of rotation of any motor, since it reverses *both* the armature and the field. The way to reverse the direction of rotation is to reverse *either* the armature or the field connection *alone*, leaving the other the same as before.

Examination before Starting. The machine should be cleaned throughout, especially the commutator, brushes, electrical connections, etc. Any metal dust on the commutator or near electrical connections should be removed, as it is very likely to cause short circuits or grounds. Examine the machine carefully, and make sure that there are no screws or other parts that are loose or out of place. See that the oil-cups have a sufficient supply of oil, that the passages for the oil are clean, and that the feed is at the proper rate. In the case of self-oiling bearings, the rings or other means for carrying oil should work freely. See that the belt, if used, is in place, and that it has the proper tension. If the machine is being started for the first time, it should be turned a few times by hand, or run very slowly, in order to determine whether the shaft revolves easily and the belt runs on centers of pulleys.

The brushes should be carefully examined, and adjusted to make good contact with the commutator at the proper point, the switches connecting the machine to the circuit being left open. The machine should then be started with care, and brought up to full speed gradually, if possible. The person who starts either a dynamo or a motor should closely watch the machine and everything connected with it, and should be ready to throw it out of circuit and stop it instantly if the least thing seems to be wrong. He should then be sure to find out and correct the trouble before starting again.

Starting a Generator. A generator is usually brought up to speed either by starting its engine or other prime mover, or by connecting it to a source of power already in motion, The former should be attempted only by a person competent to manage steam engines or the prime mover in question. The mere mechanical connecting of a generator to a source of power is usually not difficult; but it should be done carefully and intelligently, even if it only requires throwing in a friction-clutch or shifting a belt from an idle pulley. To put a belt on a pulley in motion is difficult and dangerous, particularly if the belt is large or the speed is high; and should not be tried except by one who knows just how to do it. Even if a stick is used for this purpose, it is apt to be caught and thrown around by the machinery unless used in exactly the right way.

In many cases generators are brought to full speed before the brushes are put in contact with the commutator; but this is not necessary. If the brushes are in contact before starting, they can be more easily and perfectly adjusted, and the E. M. F. will come up slowly, so that any fault or difficulty will develop gradually and can be corrected, or the machine stopped, before any injury is done. In fact, if the machine is working alone on a system, and is absolutely free from any danger of short-circuiting any other machine or storage battery on the same circuit, it may be started while connected to the circuit, but not otherwise (see next article). With a large number of lamps connected to the circuit, the field magnetism and voltage might not be able to "build up" until the line is disconnected.

If one generator is to be connected to another or to a circuit having other generators or a storage battery working upon it, the greatest care should be taken. This coupling together of generators can be done perfectly, however, if the correct method is followed, but is likely to cause serious trouble if any mistake is made.

Two or more machines are often connected to a common circuit. This is especially the case in central stations where the load varies so much that, while one generator may be sufficient for certain hours, two, three, or more machines may be required at other times. The various ways in which this is done depend upon the character of the machines and of the circuit.

Generators may be connected together either in parallel or in series.

Generators in Parallel. In this case the + (positive or plus) terminals are connected together or to the same line, and the - (negative or minus) terminals are connected together or to the other line. The currents (*i. e.*, amperes) of the machines are thereby added, but the E. M. F. (volts) is not increased. The chief condition for the running of generators in parallel is that their voltages shall be equal, but their current capacities may be different.

For example: A generator producing 10 amperes may be connected to another generating 100 amperes, provided the voltages agree. Parallel working is therefore suited to constant-potential circuits. A generator to be connected in parallel with others or with a storage battery, must first be brought up to its proper speed, E. M. F., and other working conditions; otherwise it will short-circuit the system, and might burn out its armature. Hence it should not be connected to a circuit in parallel with others until its voltage has been tested and found to be equal to, or slightly (not over 1 or 2 per cent) greater than, that of the circuit. If the voltage of the dynamo is less than that of the circuit, the current will flow back through it and cause it to run as a motor. The direction of rotation is the same, however, if it is shunt-wound; and no great harm results from a slight difference of potential; but compound-wound machines require more careful handling.

Direct-Current Dynamos in Parallel are always Shunt-Wound (or Compound-Wound). The test for equal voltages may be made by first measuring the E. M. F. of the circuit and then of the machine by one voltmeter; or two voltmeters, one connected to each, may be compared (Fig. 18); or a differential voltmeter may be used. Another method is to connect the dynamo to the circuit through a high resistance and a galvanometer; and when the latter indicates no current, it shows that the voltage of the dynamo is equal to that of the circuit. A rougher and simpler way to do this is to raise the voltage of the dynamo until its "pilot-lamp," or other lamp fed by it, is fully as bright as the lamps on the circuit, and then to connect the dynamo to the circuit. Of course the lamps compared should be intended for the same voltage and in normal condition. Be sure to connect the positive terminal of the dynamo to the positive conductor, and the negative terminal to the negative conductor (Fig. 18); otherwise there will be a very bad short circuit.

When the dynamo is first connected in this way, it should supply only a small amount of current to the circuit (as indicated by its ammeter), and its voltage should then be gradually raised until it generates its proper share of the total current; otherwise it will cause a sudden jump in the brightness of the lamps on the circuit.

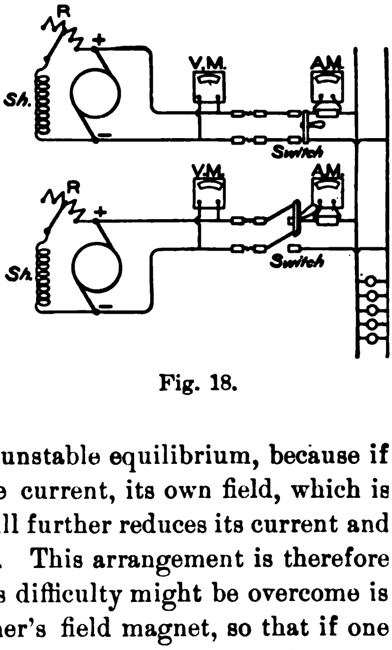


Fig. 18.

Series-Wound Dynamos in Parallel Not Used. If the machine is series-wound, the back current just described would cause a reversal of field magnetism and a very bad short circuit of double voltage. In fact, series dynamos in parallel are in unstable equilibrium, because if either tends to generate too little current, its own field, which is in series, is weakened, and thus still further reduces its current and probably will reverse the machine. This arrangement is therefore not used. One way in which this difficulty might be overcome is by causing each to excite the other's field magnet, so that if one generates too much current, it strengthens the field of the other and thus counteracts its own excess of power.

Another plan is to excite both fields by one machine, or, better, by both machines jointly, which is accomplished by connecting together the two + brushes and the two – brushes respectively, by the line and by what is called an **equalizer** (Fig. 19). In this way the electrical pressure at the terminals of the two armatures is made the same, and the currents in the two fields are also made equal. Series machines are not often run in parallel, but the principles just explained help the understanding of the next case, which is very important.

Compound Dynamos in Parallel. Since the field magnets of these machines are wound with series coils as well as with shunt coils, the coupling of them is a combination of the shunt and series cases just described.

The manner of connecting two or more compound dynamos to operate in parallel is represented in Fig. 19, A being the armature, B the series, and C the shunt-field coils. R is the shunt-field rheostat; D and F are switches connecting the main terminals of the machine with the bus bars G and I, respectively; and E is a switch to connect the equalizer H with the brush end of the series coil B.

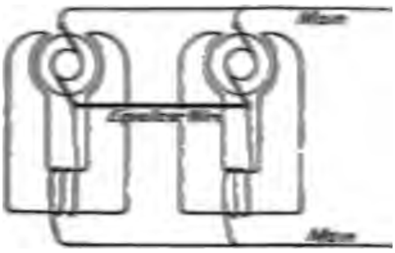


Fig. 19.

Assume that machine No. 1 is already in operation with its switches D, F, and E closed, and that it is desired to have machine No. 2 thrown in circuit. The procedure is as follows:

Bring machine No. 2 up to its rated speed, and adjust its pressure by means of the shunt-field rheostat until it is a little greater about 1 per cent than the difference of potential between the bars G and I. This fact may be ascertained by comparing two voltmeters connected to the dynamo and to the bus bars respectively; or by means of a single voltmeter connected through a double-throw switch, first to one and then to the other, which avoids the error due to a difference between two instruments. Another plan is to employ a differential voltmeter, that is, one having two windings on the movable coil, so that it indicates directly the difference in voltage between the two parts of the system.

After the pressure of the *incoming* dynamo has been properly regulated, the three switches E, F, and D are closed in the order named. If these points should be closed simultaneously by means of a triple-pole switch, a considerable current might flow through the series field winding, tending to increase still further the voltage of this dynamo, at the same time taking current away from the series coils of the other machines, and thereby reducing their potential. The shifting of the load thus produced might be so sudden and so great as to be objectionable. This action, however, is not of sufficient importance to overbalance the many advantages afforded by the use of a switch in which the three are combined as a triple-pole switch, thus guarding against the possibility of any accident due to closing the wrong circuit first.

After the machines have been thrown in parallel, their voltages should be adjusted by the shunt-field rheostats so that the load is properly divided between them.

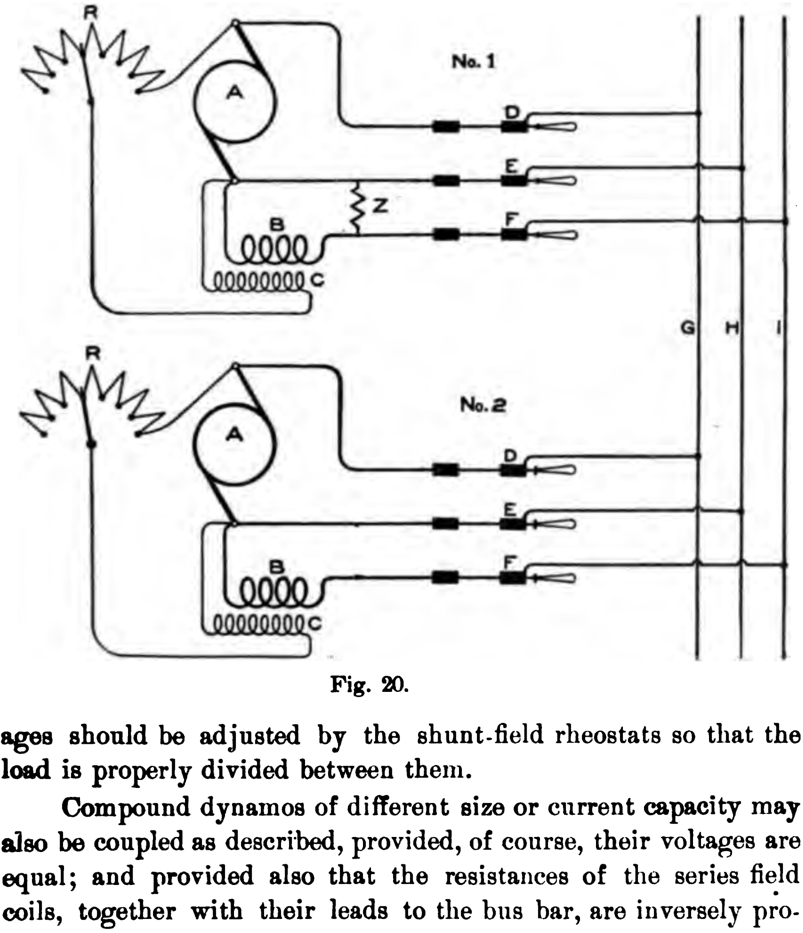


Fig. 20.

Compound dynamos of different size or current capacity may also be coupled as described, provided, of course, their voltages are equal; and provided also that the resistances of the series field coils, together with their leads to the bus bar, are inversely proportional to the current capacities of the several machines; that is, if a dynamo produces twice as much current, its series coil and lead should have half the resistance. It is further necessary that the two machines should agree in their action, so that a given increase in load will produce the same effect upon their voltages.

If they are not in agreement, they may be adjusted by slightly increasing the resistance of the series coil of that machine which tends to take too large a share of the load. This may be done by simply interposing a few extra feet of conductor of the same current capacity as the series coil, between the latter and the main conductor or bus bar. The shunts which are almost always used to adjust the effect of the series coils in compound dynamos (shown at Z in machine No. 1, Fig. 20), operate properly in the case of machines working *singly*, but are worthless for machines in parallel. The *resistances of the series coils themselves* must be adjusted as explained above, when two or more compound machines are run in parallel. The use of iron for this shunt makes the compounding effect in the dynamo more uniform, because its resistance, rising as the current through it increases, throws a greater fraction of the current through the series coils at full load, and compensates for the fact that the field magnetism, and consequently the voltage, does not increase proportionately with the increasing load current.

Shunt-wound dynamos run in parallel tend to steady each other, for, if one happens to run too fast, it has to do more work, which opposes the increase of speed ; and it also takes part of the load off the other machines, which makes them run faster, thus producing equality. This mutual regulation will take care of any slight difference between machines, such as that caused by the slip of the belt, or even small differences in the governing action of the different engines that may be driving them. Compound-wound dynamos have very much less mutual regulation, owing to the effect of the series coil ; and it is necessary that their speeds, voltages, etc., should regulate much more exactly than with simple shunt machines. They often work badly together owing to carelessness or to imperfect agreement between them, but with proper care and good apparatus they run well in parallel.

If generators are located at considerable distances from the switchboard, the equalizing connection may be run directly from one machine to the other with the equalizing switch (E, Fig. 20) on the frame of each, instead of running to the switchboard. This saves copper, especially in the case of large generators.

Alternators in Parallel. To run two alternators in parallel, several conditions have to be fulfilled: The incoming machine—as in the case of direct-current machines—must be brought up to nearly the same voltage as the first one; it must operate at exactly the same frequency; and, at the moment of switching in parallel, it must be in phase with the first machine. This correspondence of frequency and phase is called **synchronism.**

It is impossible with mechanical speed-measuring instruments to determine the speed as accurately as is necessary for this purpose. There is, however, a very simple method of electrically determining small differences in speed or frequency. In Fig. 21, let M and N represent two single-phase alternators, which can be connected by means of the single-pole switch AB Across the terminals of the switch is connected an incandescent lamp L, capable of standing twice the voltage of either machine. When AB is open, the circuit between the machines is completed through L. The two machines may be connected in parallel as follows: Assuming machine M already in operation, bring up machine N to approximately the proper speed, and voltage; then watch lamp L. If machine N is running a very little slower or faster than machine M, the lamp L will glow for one moment and be dark the next. At the instant when the voltages are equal in pressure and phase, L will remain dark; but when the phases are displaced by half a period, the lamp will glow at its maximum brilliancy. Since the flickering of the lamp is dependent upon the difference in frequency, the machines should not be thrown in parallel while this flickering exists. The prime mover of the incoming machine must be brought to the proper speed; and the nearer machine N approaches snychronism, the slower the flickering. When it is very slow, we can use the moment the lamp is dark to throw the machines in parallel by closing the switch across AB. The machines are then in phase, and tend to remain so, since if one slows down the other will drive it as a motor. It is better to close the switch when the machines are approaching synchronism than when they are receding from it, that is, at the instant the lamp becomes dark.

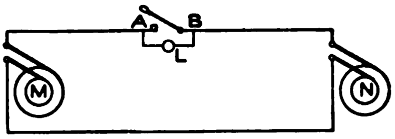


Fig. 21

This method of synchronizing is open to the following objections:

(*a*) The lamps may be dark with considerable difference in voltage. For instance, a 110-volt lamp is dark with a pressure of 20 to 25 volts.

(*b*) The lamp may be dark owing to a broken filament.

It may thus happen, with this arrangement, that the machines are placed in parallel while there is a considerable difference of voltage or phase existing, and an excessive rush of current will result.

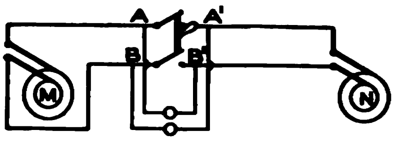


Fig. 22.

A method not open to the above objections is shown in Fig. 22. The machines to be switched in parallel are each connected to the bus bars by means of double-pole switches. Two incandescent lamps, of the machine voltage, are cross-connected as shown. If the machines are in phase and the voltages generated are equal in value, the difference of potential between A and a given point is the same as that between A' and the same point; likewise B and B' have the same relative potential values. Hence a lamp connected between A and B' would burn with the same brilliancy as if it were connected directly across AB; likewise with the other lamp. If, however, the machines happen to be directly opposite in phase but to be generating voltage of the same value, A and B' are of the same relative potential value, and B and A' are likewise of the same value; hence lamps cross-connected as in Fig. 22 would be dark. At any other phase difference the lamps will glow, but not so brightly as when in phase. Hence, with this arrangement, the machines should be thrown in parallel when the lamps are on the verge of maximum brightness, a condition readily determined, but not possible with the first method.

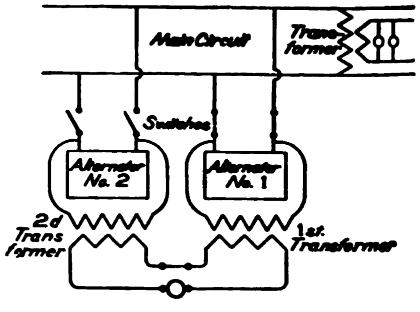


Fig. 23.

The connections as shown in Figs. 21 and 22 are not directly applicable to high-tension working, but require the introduction of transformers as shown in Fig. 23, which is a modification of Fig. 22. The secondaries (of, say, 50 volts each) should be connected in series with each other and to one 100-volt lamp. When the two machines are opposed in phase, the lamp is dim. If the lamp flickers badly, the phase is not right; but if the lamp is steady at full brightness, the machines are in phase, and they may be connected without disturbing the circuit, by closing the main switch.

If alternators are rigidly connected to each other or to the engine, so that they necessarily run exactly together, there is no need of bringing them into step each time, but they should be adjusted to the same phase in the first place.

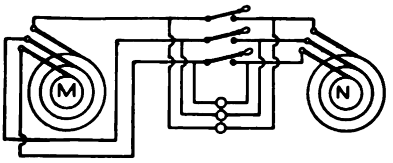


Fig. 24.

The connections of the synchronizing lamps of a three-phase system are similar to those for a single-phase system. For instance, the method employed in Fig. 21 may be extended, and lamps connected as in Fig. 24. If the three lamps simultaneously become dark or bright, the connections are correct, and the three switches may be closed at an instant of darkness. It may happen, however, that the lamps do not become bright or dark simultaneously but successively This indicates that the order of connection of the leads of one machine does not correspond with that of the other. In this case, transpose the leads of one machine until the proper or simultaneous action of the lamps is obtained. After the machines have been properly connected, it is sufficient to synchronize with one of the lamps. Similarly, with high-tension systems, only a single-phase transformer is required, connected as shown in Fig. 25.

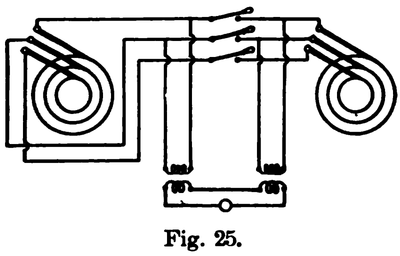


Fig. 25.

Generators in Series. This arrangement is less common than parallel working, and does not usually operate so well, except with series-wound machines on arc circuits, which is very successful. The conditions are exactly opposite to those in the preceding group—generators in parallel.

To connect machines in series, the positive terminal of one must of course be connected to the negative terminal of the next, and so on. Each must have a current capacity equal to the maximum current on the circuit, but they may differ to any extent in E. M. F. The voltages of machines in series are added together; and therefore danger to persons, insulation, etc., is increased in proportion.

Series-Wound Direct-Current Dynamos in Series are connected in the simple way represented in Fig. 26; but, usually machines connected in series are for arc lighting—for example, when two dynamos, each of 40 lights capacity, are run on one circuit of 80 lamps, in which case the dynamos usually have some

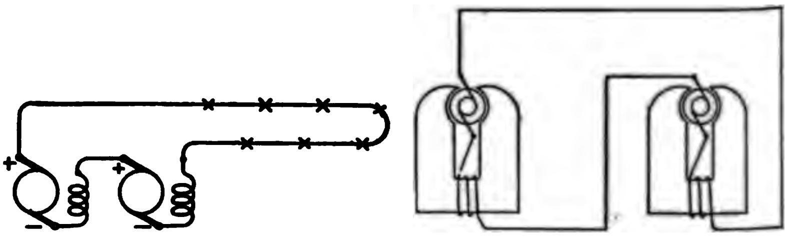


Fig. 26.

form of regulator. These regulators do not usually work well together, because they are apt to "seesaw" with each other. This difficulty may be overcome either by connecting the regulators so that they work together, or by setting one regulator to give full E. M. F. and letting the other alone control the current. This latter plan can be followed only when the variation in load does not exceed the power of one machine. Constant-current dynamos having regulators with little inertia in the moving parts, and thus little tendency to "overshoot," such as the Brush machine, can be run in series without much trouble.

Shunt or Compound Dynamos in Series run well, provided the shunt-field coils are connected together to form one shunt across both machines. If the machines are compound, all of the series coils must be connected in series with the main circuit. Another plan is to connect each shunt field so that it is fed only by the armature of the other machine ; or both the shunt coils may be connected so as to be fed by one armature, the series coils being in the main circuit as before.

Alternators in Series. The synchronizing tendency which makes it possible to run alternators in parallel, causes them to get out of step and become opposed to each other when it is attempted to run them in series. It is therefore impracticable to run them in series unless their shafts are rigidly connected so that they must run exactly in phase and thus add their waves of current instead of counteracting each other. This case rarely occurs.

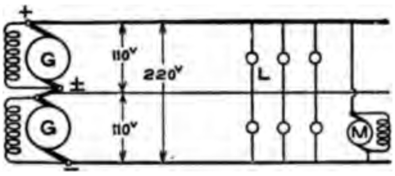


Fig. 27*a*.

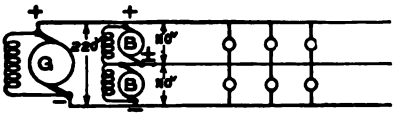


Fig. 27*b*.

Dynamos on the Three-Wire System (Direct-Current). In the ordinary three-wire system for incandescent lighting and power service, no particular precautions are required in starting or connecting the machines; and either of the two arrangements shown in Figs. 27*a* and 27*b* may be adopted. The two sides of the system are almost independent of each other, and form practically separate circuits, for which the middle or neutral wire acts as a common conductor. There is, however, a tendency for the dynamos (Fig. 27*a*) to be reversed in starting up, in shutting down, or in the case of a severe short circuit. This can be avoided by exciting the field coils of all the dynamos from one side of the system, or from a separate source. To obtain good regulation, it is necessary to balance the load equally on both sides of the system. It is advisable to employ 220-volt motors on 110-volt 3-wire systems, and to connect them across the outside conductors so that the motor load shall not unbalance the system.

KINDS OF MOTORS, CONNECTIONS, AND STARTING.

The general instructions relating to the adjustment of brushes, screws, belt, oil-cups, etc., given in relation to the generator, should be carefully followed preparatory to starting a motor. The actual starting of a motor is usually a simple matter, since it consists merely in operating a switch; but in each case there are one or more important points to be considered

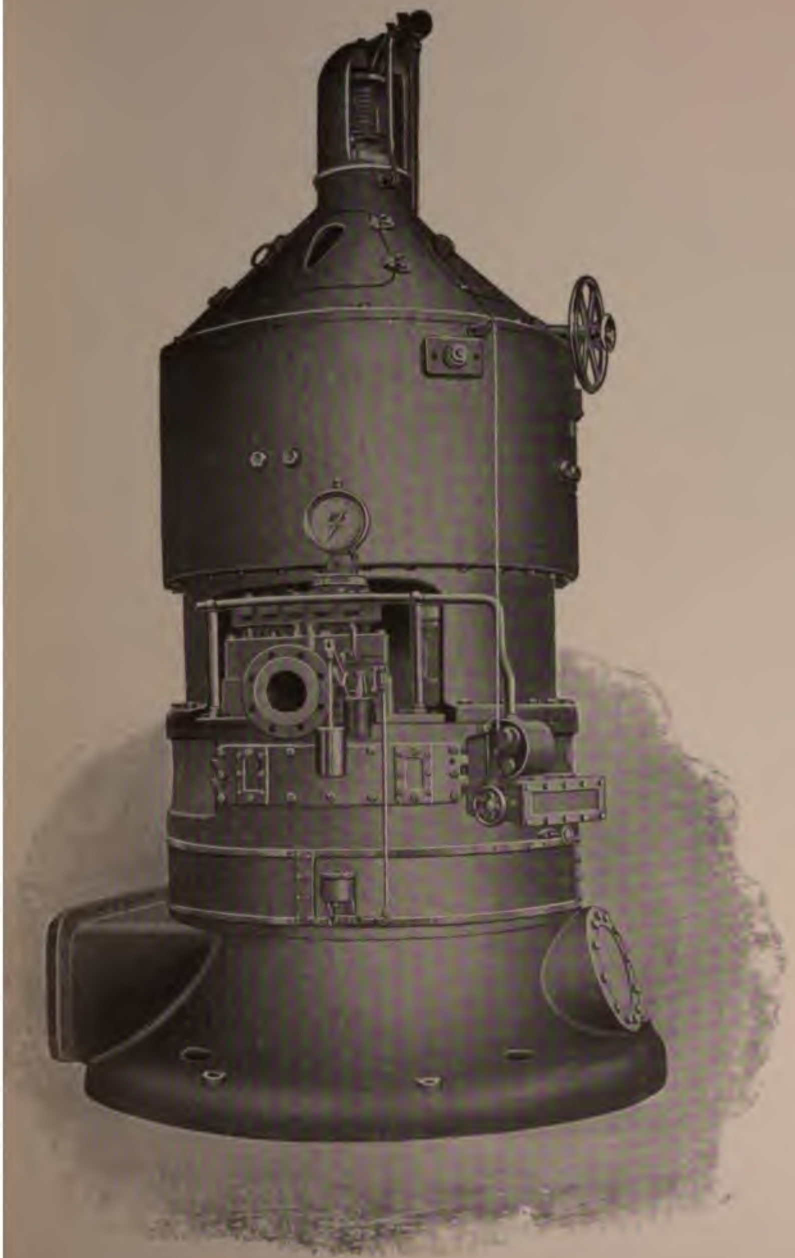
CONSTANT-POTENTIAL D. C. CIRCUITS.

Shunt-Wound Motor. A motor to operate at nearly constant speed, with varying loads, on a D. C. constant-potential system (110- or 220-volt lighting circuits) is usually plain shunt-wound. This is the commonest form of stationary motor. The field coils are wound with wire of such a size as to have the proper resistance and resulting magnetizing current; and since the potential applied is practically constant, the field strength is constant.

In starting shunt motors, no trouble is likely to occur in connecting the field to the circuit. The difficulty is with the armature current, because the resistance of the armature is very low in order to get higher efficiency and constancy of speed, and the rush of current through it in starting might be twenty or more times the normal number of amperes. To avoid this excessive current, motors are started on constant-potential circuits through a rheostat or "starting-box" containing resistance coils.

The main wires are connected through a branch cut-out (with safety fuses), and preferably also a double-pole knife switch Q, to the motor and box, as indicated in Fig. 28. When the switch Q is closed, the arm S being in its left-hand position, the field circuit is closed through the contact stud *f*, and the armature circuit is closed through the resistance coils *a*, *a*, *a*, which prevent the rush of current referred to. The motor then starts, and as the speed rises it generates a counter E. M. F., so that the arm S can be turned as shown until all the resistance-coils *a*, *a*, *a*, are cut out, and the motor is directly connected to the circuit and running at full speed. The arm S should be turned slowly enough to allow the speed and counter E. M. F. to come up as the resistances *a*, *a*, *a* are cut out. The arm S should positively close the field circuit first, so that the magnetism reaches its full strength (which may take several seconds) before the armature is connected.

In the arrangement shown in Fig. 28 the release magnet has its coils in series with the field. As long as the motor is in operation, the core is energized and the arm S is held in the posi-



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ı shown. If, however, the current supplied to the motor is off and the motor comes to rest, the core of the magnet loses attractive force, and the arm S is released, being automatically ved back to the starting position by a spring.

The coils a, a, a are made of comparatively fine wire, which ı carry the current only for a few seconds in a "starting-box;"

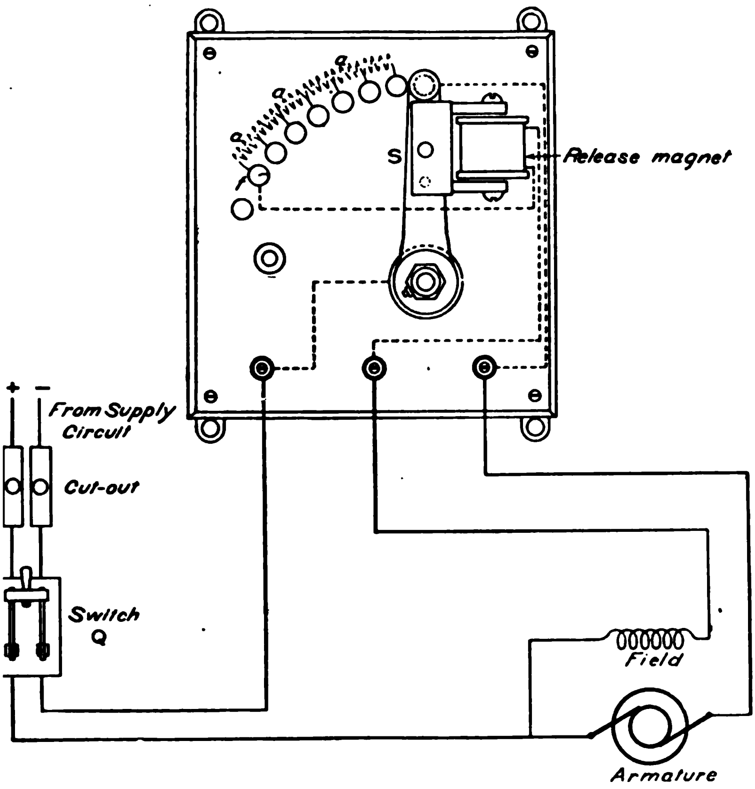


Fig. 28.

t if the wire is large enough to carry the full current continu-sly, it is called a "regulator," because the arm S may be left so ıt some of the resistances a, a, a remain in circuit, and they will ve the effect of reducing the speed of the motor, which is often ry desirable.

In some cases where a circuit is used exclusively for a single ›tor, the speed is regulated without heavy resistances by varying the E. M..F. of the dynamo which supplies the circuit. The dynamo regulator is then placed near the motor. The advantage is that the regulator is not compelled to control a heavy current, but a special circuit of unvaried pressure must be provided to keep the field of the motor constant.

The speed control of a shunt motor may be simply obtained as follows:

a. For lower speeds, insert resistance in series with the armature circuit. The resulting I. R. drop reduces the value of the voltage applied to the armature terminals, and thus reduces the speed.

b. For higher speeds, insert resistance in the shunt-field circuit. This reduces the magnetic flux, and to generate the same C. E. M. F. the motor must speed up.

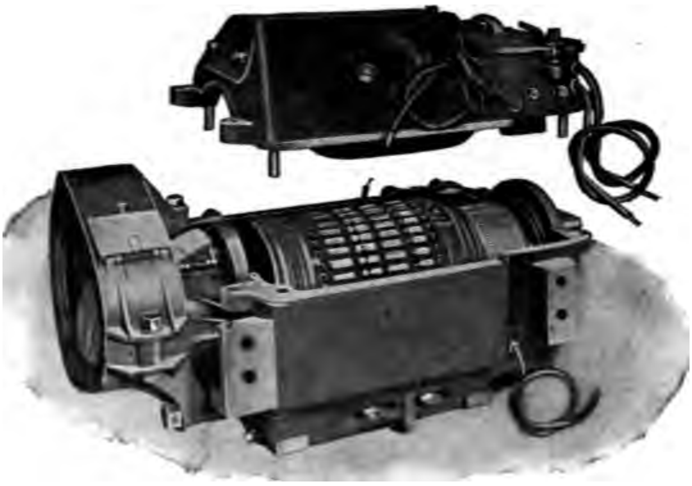


Fig. 29.

The field circuit of a shunt motor should never be opened while pressure is still applied to the armature terminals, as under these conditions the armature current becomes very excessive and the armature is likely to race and probably be damaged. A moderate decrease in field strength only is allowable; otherwise sparking becomes excessive.

Series-Wound Motor. The ordinary electric railway motor on the 550-volt trolley system is the chief example of the class (Fig. 29.) Motors for fans, pumps, or electric elevators and hoists are either of this kind or of the compound type. A rush of current tends to occur when the series type of motor is started, similar to that in the case just described; but it is less, because the field-coils are in series, so that their resistance and self induction reduce the excess. Furthermore, the counter E. M. F. is greater even at low speed because the heavy current produces a strong field.

The connections as indicated in Fig. 30 are very simple, the armature, field-coils, and rheostat all being in series and carrying the same current.

The series-wound motor on a constant-potential circuit does not have a constant field strength, and does not tend to run at constant speed, like a shunt motor. In fact it may "race" and tear itself apart if the load is taken off entirely; it is therefore suited only to railway, pump, fan, or other work where variable speed is desired, or where there is no danger of the load being removed or a belt slipping off. It is also used where the potential is subject to sudden and large drops, as on the ends of long trolley circuits, because in such a case a shunt motor becomes momentarily a generator and sparks very badly. The fields of series motors are sometimes "overwound," that is, so wound that they will have their full strength with even one-half or one-third of the normal current. The objects are to secure a nearly constant speed with varying loads, to enable the motor to run at high efficiency when drawing small currents, and to prevent sparking at heavy loads.

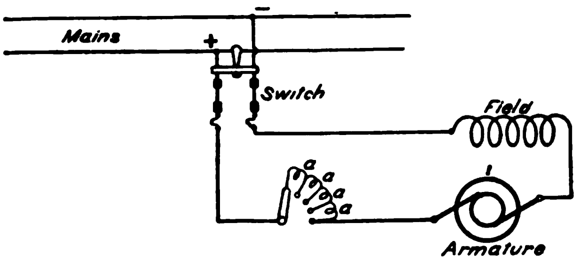
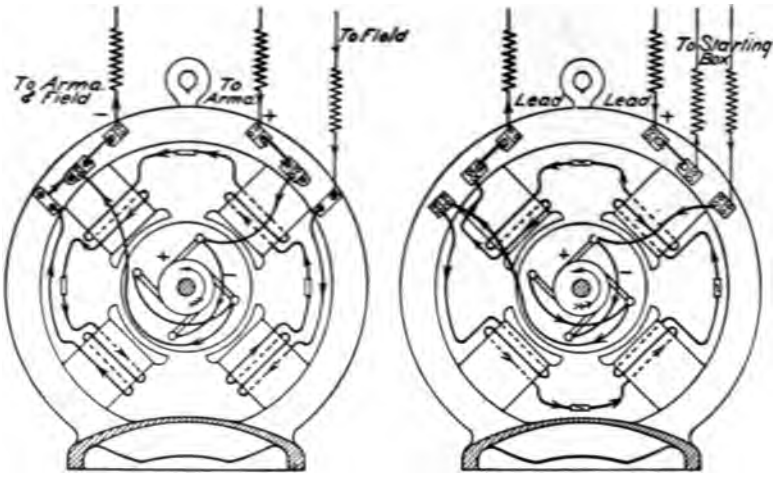


Fig. 30.

In multipolar motors having more than two field-coils, the coils are all connected together, and are equivalent to the single pairs of coils shown in the several diagrams. Being separated, however, it is sometimes necessary to trace out the connections. Fig. 31 represents the necessary connections for a four-pole motor, shunt-wound and series-wound.

Differentially-Wound Motor. This is a shunt-wound motor with the addition of a coil of large wire, on the field, connected in series with the armature in such a way as to oppose the magnetizing effect of the shunt winding and weaken the field, thus causing the motor to speed up when the load is increased, as an offset to the slowing-down effect of load.

It was formerly used, for obtaining very constant speed, but it has been found that a plain shunt motor is sufficiently constant for almost all cases. The differential motor, if overloaded, has the great disadvantage that the current in the opposing (series) field-coil becomes so great as to kill the field magnetism; and instead of increasing or keeping up its speed, the armature slows down or stops, and is likely to burn out; whereas a plain shunt motor can increase its power greatly for a minute or so when overloaded, and will probably throw off the belt or carry the load until the latter decreases to the normal amount.



Shunt-wound Motor. Series-wound Motor.

Fig. 31.

Compound-Wound Motor. This type of motor is also provided with a shunt and a series-field winding, Fig. 32, but in this instance they magnetize the field in the same direction, or, in other

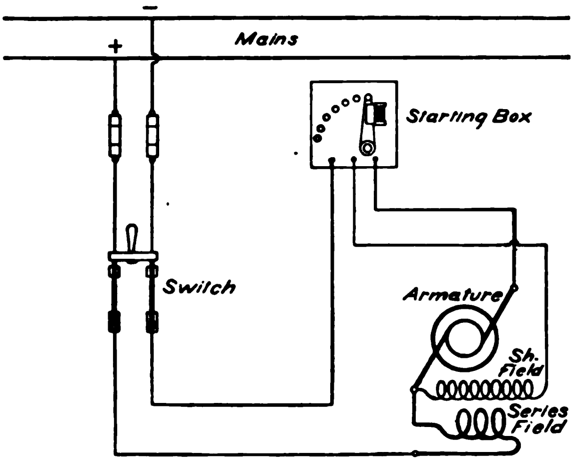


Fig. 32.

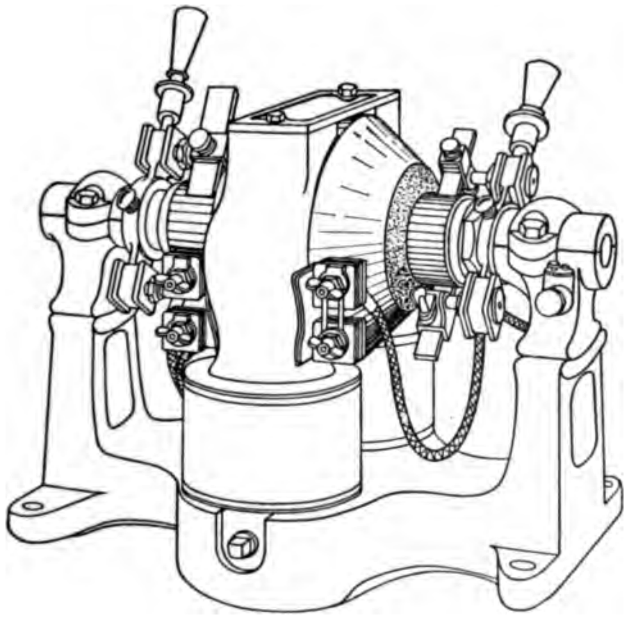


Fig. 33.

words, their effect is cumulative. This type of motor possesses the powerful starting torque feature of the series motor, but a less variable speed with varying loads. It is employed where a great starting torque and a fairly uniform running speed are required, as, for example, with electric hoists or elevators.

Dynamotors, Fig. 33, and also motor-generator sets, are started in the same way as motors; that is, the motor portion of the machine is connected to the circuit and operated precisely like the corresponding kind of motor. Usually the motor part is plain shunt-wound, and is supplied with current from a constant-potential circuit. It is therefore connected and started in the manner shown and described on page 40.

The current generated by the dynamo portion of the dynamotor may be taken from the terminals, and used for any purpose to which it is suited. The E. M. F. or current produced may be regulated by varying the resistance in the armature circuit of either the motor or dynamo. In case the dynamo armature has a separate field magnet, the E. M. F. and current may be controlled by regulating the magnetic strength of this field, or the machine may be compounded or even "over-compounded." But if the armatures of both motor and dynamo are acted upon by the same field, the E. M. F. of the dynamo cannot be varied except by inserting resistances in the circuit of either armature or by shifting the brushes. But the latter method will be likely to cause sparking.

ALTERNATING-CURRENT MOTORS.

Alternating-current motors operate on constant-potential circuits, since almost all A. C. systems are of this kind. There are several types of these motors, the simplest of which is the *series machine* for single-phase current. This is similar to the corresponding D. C. motor, except that its field must be laminated.

It possesses the characteristic of large starting torque and lends itself to variable speed control like its direct current counterpart and is coming into use very rapidly for electric railway work. Both the General Electric and the Westinghouse Electric and Manufacturing Companies have placed such machines upon the market and they are already in operation on a number of electric roads where they are giving satisfaction.

This type of motor while retaining practically all the advantages of the direct-current series motor for electric railway work permits the use of alternating current on the trolley with all its attendant advantages. A frequency of 25 seems likely to become the standard for such work. The cars can be operated on existing direct-current lines and the multiple unit control system can be applied to cars equipped with single-phase motors.

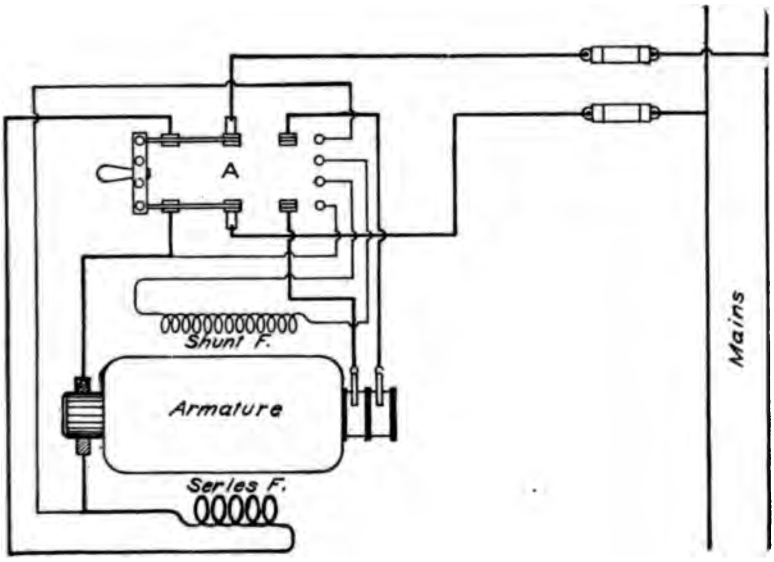


Fig. 34.

An ordinary single-phase alternator can be used as a motor; but it must first be brought up to synchronism with the supply generator by means of some auxiliary starting device (steam engine, polyphase induction motor, etc.) before the load can be applied. In this form the machine is known as the *single-phase synchronous motor.* The condition of synchronism is determined by one of the methods described in the paragraph on "Alternators in Parallel." After the motor is in synchronism it may be connected to the circuit by closing its supply switch; and it will then continue to run at an absolutely constant speed, unless heavily overloaded, when it falls out of step and stops.

On account of these features, the synchronous motor is not to be recommended for general application. Various manufacturers, notably the Wagner Electric Company, and the Fort Wayne Electric Company, manufacture self-starting, single-phase synchronous motors, usually limited, however, to the smaller sizes. The construction and action of the Fort Wayne motor (Fig. 34), which is a combination of the two preceding types, are as follows: The armature core is provided with a double winding, one equipped with collecting rings, and the other with an ordinary commutator. The field magnet, which is laminated, is wound with two separate circuits, one being of low resistance and a small number of turns, the other of high resistance and many turns, like an ordinary shunt-field winding. In starting, the motor runs as a series machine, the low-resistance field being in series with the commutated armature winding and the line. When it has reached synchronism, the switch A, on the top, is thrown over to the right, and the supply line connected with the collector rings and the corresponding armature winding; while the commutated end is connected to the other field winding, and thus provides the direct current necessary for field excitation.

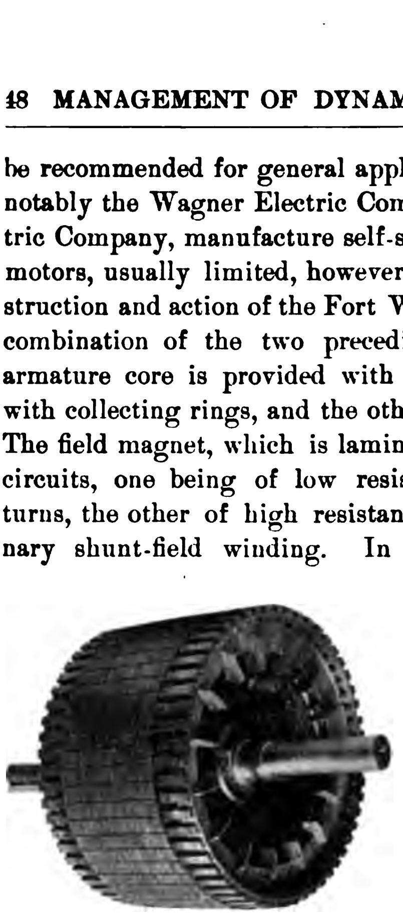


Fig. 35.

In addition to the single-phase there is also the *polyphase synchronous motor*. This latter form, however, is self-starting without field current, but will not carry a load until it is running in synchronism. When this condition is reached, the field circuit should be closed before applying the load.

A great advantage of the synchronous motor is that when its field is over-excited, it draws a leading current from the line, thus acting like a condenser and tending to neutralize the inductive effect of other machinery, so that the power factor of the whole system is raised. The most extensive use of the synchronous motor is as a part of the rotary converter, which is employed to convert alternating into direct currents, for traction and electro-chemical purposes.

The satisfactory use of alternating currents for power purposes depends mainly on the *polyphase induction motor*, as in this form the A. C. motor is self-starting with considerable torque and operates at a practically constant speed from no load to a heavy overload. Induction motors are designed for the standard voltages and frequencies.

In most induction motors now built, the primary, or part into which the currents from the line are led, is the stationary member, or *stator*. The secondary, in which the induced currents are set up, is the rotating member, or *rotor*. There are two kinds of rotor windings, the simpler being that known as the "squirrel-cage." This winding is made up of a number of copper bars, equally spaced around the rotor core, and imbedded therein. The terminals of these inductors are interconnected, or short-circuited, by means of heavy copper rings placed at both ends of the core, as shown in Fig. 35.

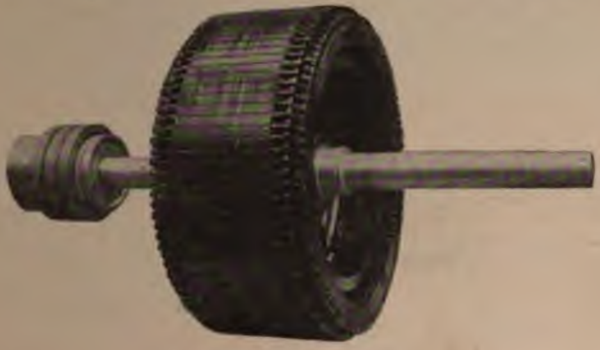


Fig. 36.

The other form of winding is of the drum species, usually three-phase, Y-connected; and the coils are located at 120° intervals (the arc between centers of adjacent poles being called 180°) with respect to each other. The free ends of the windings are respectively brought out to three slip or collecting rings; and on this account this type of rotor is frequently called the "slip-ring" rotor (Fig. 36).

Starting Induction Motors. In small sizes, up to 3 or 5 H. P., the induction motor can be started by connecting its stator terminals directly to the line. But with larger sizes the inrush of current is excessive and likely to disturb the system; accordingly some form of starting device is usually necessary.*

Starting Compensators. This inrush of current can be avoided by inserting a starting resistance, or inductance, in series with the primary winding and the line, or by using some other means of cutting down the applied E. M. F. The torque of an induction motor decreases as the square of the applied voltage, so that this method of starting results in a greatly reduced starting effort. However, in many instances, motors are not started up under full load, so that this may not be a serious objection.

While a resistance could be employed as described, it is more economical to employ an auto-transformer (that is, a transformer having but one coil, which serves as both a primary and a secondary), or *compensator*, as it is called when used for this purpose. Compensator connections for a three-phase motor are represented in Fig. 37. The compensator consists of coils *a*, *b*, and *c*, wound on a laminated-iron core, each coil being provided with a number of taps, 1, 2, 3, etc. The pressure applied to the motor at starting is proportioned to the amount of each coil included in the circuit. While the compensator winding is provided with taps, only that one which is most suitable for the work is used after the equipment is permanently installed. When the switch is in the

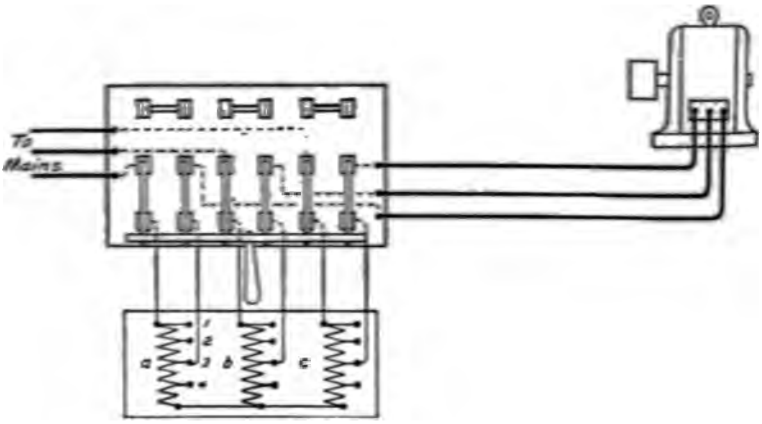


Fig. 37.

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* This inrush of current is frequently three times the rated load current.

lower position as indicated, a part of each coil is in series with each leg of the system leading to the motor; and the applied voltage is correspondingly cut down. After the motor reaches its rated speed, the switch is thrown to the upper or running position, and the stator or primary terminals are connected directly to the line. The compensator thus prevents an excessive inrush of current, and gives the motor a smooth start, although it decreases the starting torque, compared with that due to full line pressure.

Speed Regulation of Induction Motors. For some classes of work, it is desirable to have induction motors arranged so that their speed can be controlled, the usual methods being:

a. The insertion of a variable resistance in the rotor circuit.

b. Cutting down the voltage applied to the stator, as just described.

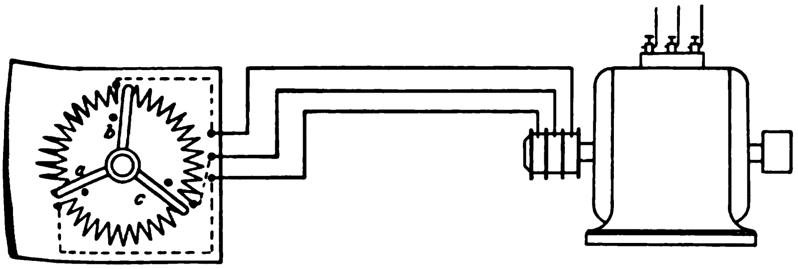

Fig. 38.

The more satisfactory method of speed control, is that with variable resistance inserted in the rotor circuit, the power-factor and hence the efficiency of the system being greater at reduced speeds than with the compensator or equivalent device. It requires, however, the use of collector rings, connecting brushes, and leads, since a resistance for continuous service is too bulky to be placed within the machine. Still further, the heat developed in the resistance would heat the machine too much. The controller itself looks like an ordinary trolley car controller, but for simplicity it is represented as a three-armed controller (Fig. 38) in which the arms *a*, *b*, and *c* are in electrical contact under the handle. The resistance is provided in three sets, one for each free end of the rotor winding; and each set is subdivided so that it can be gradually cut out of circuit as the motor speed increases. Frequently the controller is so arranged that the first motion of the handle closes the supply lines, and subsequent motions vary the resistances in the rotor circuit, thus performing the function of a supply switch and speed controller.

Another method of speed control, is to have the winding on the stator arranged so that by means of a suitable controlling switch, the number of poles can be changed. This is a very economical method from the electrical standpoint, and gives a very wide range of control, but, on account of its complexity and cost, is used only to a limited extent.

In general, the induction motor does not allow of the same range of speed control as does the direct-current motor, and the methods employed for this purpose are not efficient.

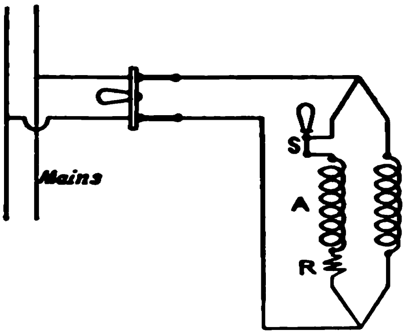

Fig. 39.

Single-Phase Induction Motor. A two or three-phase induction motor will operate fairly well, if, after reaching full speed, all but one of the phases be cut out. It will not however start from rest under the influence of single-phase excitation. Hence, to start an induction motor from the lines of a single-phase system, currents differing in phase must be obtained. This is accomplished by connecting the two primary windings A and B (in the case of a two-phase motor) in parallel to the single-phase mains, at the same time connecting in series with one winding a resistance R (Fig. 39). The currents flowing through these two windings will then differ in phase, one leading the other on account of a difference in their constants, and will thus produce a rotating field, and the motor will then start up.* When the motor has reached full speed, one phase may be cut out by opening the switch at S, and the machine will carry its load. The resistance R may be replaced to advantage by a condenser, especially on small machines. Such a machine is commonly called a "split-phase" motor.

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* This field is not a rotary field in the full sense, being elliptical in character.

DIRECTIONS FOR RUNNING GENERATORS AND MOTORS.

After any one of these machines has been properly started, it usually requires little attention while running; in fact, generators or motors frequently operate all day without any care whatever.

In the case of a machine that has not been run before or has been changed in any way, it is wise to watch it closely at first. It is also well to give the bearings of a new machine plenty of oil at first, but not enough to run on the armature, commutator, or any part that would be injured by it; and to run the belt (if used) rather slack until the bearings and belt are in easy working condition.

If possible, a new machine should be run without load or with a light one for an hour or two, or for several hours in case of a large machine; and it is bad practice to start a new machine with its full load or even a large fraction of it. This is true even if the machine has been fully tested by its manufacturer and is in perfect condition, because there may be some fault in setting it up or some other circumstance that would cause trouble. All machinery requires some adjustment and care for a certain time to get it into smooth working order.

When this condition is reached the only attention required is to supply oil when needed, keep the machine clean, and see that it is not overloaded. A generator requires that its voltage or current should be observed and regulated if it varies. The attendant should always be ready and sure to detect the beginning of any trouble, such as sparking, heating, noise, abnormally high or low speed, etc., before any injury is caused, and to overcome it. Such directions should be pretty thoroughly committed to memory in order promptly to detect and remedy any trouble when it occurs suddenly, as is usually the case. If possible, the machine should be shut down instantly when any indication of trouble appears, in order to avoid injury and give time for examination.

Keep all tools or pieces of iron or steel away from the machine while running, as they might be drawn in by the magnetism, perhaps getting between the armature and pole pieces and ruining the machine. For this reason use a zinc, brass, or copper oil-can instead of one of iron or "tin" (tinned iron)

Particular attention and care should be given to the commutator and brushes, to see that the former keeps perfectly smooth and that the latter are in proper adjustment. (See "Sparking.")

Never lift a brush while the machine is delivering current unless there are one or more other brushes on the same side to carry the current, as the spark might make a bad burnt spot on the commutator, or might burn the hand.

Touch the bearings and field coils occasionally to see whether or not they are hot. To determine whether the armature is running hot, place the hand in the current of air thrown out from it by centrifugal force.

Special care should be observed by any one who runs a generator or motor, to *avoid overloading* it, because this is the cause of most of the troubles which occur.

Personal Safety. Never allow the body to form part of a circuit. While handling a conductor, a second contact may be made accidentally through the feet, hands, knees, or other part of the body, in some peculiar and unexpected manner. For example, men have been killed because they touched a "live" wire while standing or sitting upon a conducting body.

Rubber gloves or rubber shoes, or both, should be used in handling circuits of over 500 volts.* The safest plan is not to touch any conductor while the current is on; and it should be remembered that the current may be present when not expected, owing to an accidental contact with some other wire or to a change of connections. Tools with insulated handles, or a dry stick of wood, should be used instead of the bare hand.

The rule to use *only one hand* when handling dangerous electrical conductors or apparatus is a very good one, because it avoids the chance, which is very great, of making contacts with both hands and getting the current through the body. This rule is often made still more definite by saying, "Keep one hand in your pocket," in order to make sure not to use it. The above precautions are often totally disregarded, particularly by those who have become careless through familiarity with dangerous currents. The result has been that *almost all persons accidentally killed*

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* These articles should be subjected to tests at frequent intervals, so as to determine their condition.

by artificial electricity have been experienced linemen or station men.

Stopping Generators or Motors. This is accomplished by following substantially the same directions as for starting them, but in the reverse order.

A generator operating alone on a circuit can be slowed down and stopped without touching the switches, brushes, etc., in which case the current gradually decreases to zero; and then the connections can be opened without sparking or any other difficulty.

However, when a generator is operating in parallel with others, or with a storage battery, it must not be stopped or reduced in speed, until it is entirely disconnected from the system, otherwise it will act as a short circuit. Furthermore, the current generated by it should be reduced nearly to zero before its switch is opened. This is accomplished by adjusting the field rheostat of the machine to be cut out, great care being taken that the change is gradual. If the reduction be rapid, the voltage of the machine may drop so low as to cause a back current to flow.

A **constant-current generator** may be cut into or out of circuit in series with others, and can be slowed down or stopped; or its armature or field coils may be short-circuited to prevent the action of the machine, without disconnecting it from the circuit. *It is absolutely necessary, however, to preserve the continuity of the circuit*, and not to attempt to open it at any point, as this would produce a dangerous arc. Hence a by-path must be provided by closing the main circuit around the generator, before disconnecting it. This same rule applies to any lamp, motor, or other device on a constant-current system.

Never, except in an emergency, should any circuit be opened when heavily loaded, for the reason that the flash at the contact points, discharge of magnetism, and mechanical shock which result, are decidedly objectionable.

A Constant-Potential Motor is stopped by turning the starting-box handle back to the position it had before starting (Fig. 28); or, *if there is a switch Q, connecting the motor to the circuit*, as there always should be, it should be opened, after which the starting-box handle is moved back to be ready for starting again.

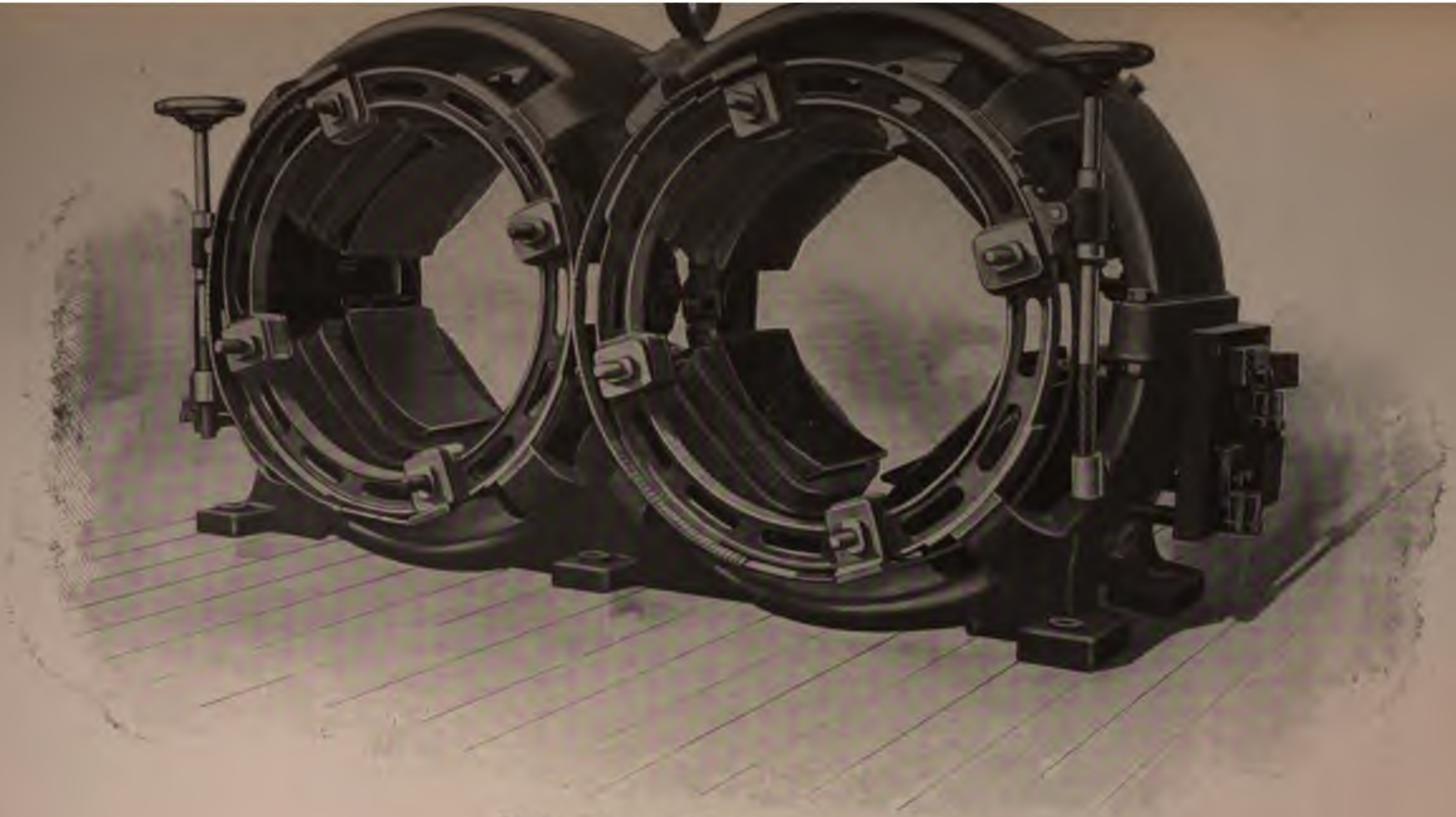
Immediately after a machine is stopped, it should be thoroughly cleaned, and put in condition for the next run. When not in use, machines should, when feasible, be protected from dirt and moisture by covers of some waterproof material.

INSPECTING AND TESTING.

Adjustment and the other points which depend merely upon mechanical construction, are hardly capable of being investigated by a regular quantitative test, but they can and should be determined by thorough inspection. In fact a very careful examination of all parts of a machine should always precede any test of it. This should be done for two reasons: first, to get the machine into proper condition for a fair test; and, second, to determine whether the materials and workmanship are of the best quality and satisfactory in every respect. A loose screw or connection might interfere with a good test; and a poorly fitting bearing, brush-holder, [illegible] other part might show that the machine was badly made.

If it is necessary to take the machine apart for cleaning or inspection, the greatest care should be exercised in marking, numbering, and placing the parts, in order to be sure to get them together exactly the same as before. In taking a machine apart or putting it together, [illegible] force should be used. Much force [illegible] is being done. A wooden or raw[illegible] hammer, since it does not bruise [illegible] parts. [illegible] screws, nuts, and other parts should [illegible] tight, but not tight enough to run any risk of [illegible] anything. Shaking or trying each screw or [illegible] will show whether any of [illegible] out of adjustment.

Friction. [illegible] of the bearings and brushes can be tested [illegible] turning the armature by hand, or [illegible] if it requires more than the normal [illegible] is quite easily distinguished. [illegible] Another method is to revolve the [illegible] and see if it continues to revolve [illegible] A well-made machine in good condition [illegible] full speed, will continue to run for [illegible] force is removed.



FIELD FRAME 200 K.W., D.C. GENERATOR.

De Laval Steam Turbine Co.

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A method for actually measuring the friction consists in at- hing a lever (a bar of wood, for example) to the shaft or pulley right angles to it. The force required to overcome the friction l to turn the armature without current, is then determined by wn weights or, more conveniently, by an ordinary spring nce. For convenience in dividing by the length of the lever, to determine the value of the friction compared with the power he machine, it should be exactly 1, 2, or 4 feet long. The tion of the bearings alone—that is, the pull which is required urn the armature when the brushes are lifted off the commu- r—should not exceed about 2 per cent of the total torque or ning force of the machine at full load. When the brushes in contact with the commutator with the usual pressure, the ction should not then exceed about 3 per cent; that is, the ushes themselves should not consume more than 1 per cent of e total turning force.

Another method of measuring the friction of a machine is to n it by another machine used as a motor, and determine the lts and amperes required, first, with brushes lifted off, and second, ith brushes on the commutator with the usual pressure. The rque or force exerted by the driving machine is afterwards asured by a Prony brake in the manner described hereafter for ting torque, care being taken to make the Prony brake meas- ments at exactly the same volts and amperes as were required the friction tests. In this way the torques exerted by the driv- machine to overcome friction in each of the first two tests are ermined; and these torques, compared with the total torque of machine being tested, should give percentages not exceeding se stated above for maximum values of friction. The magnetic ll of the field on the armature may be very great if the latter is t exactly in the center of the space between the pole pieces. is would have the effect of increasing the friction of the shaft the bearings when the field is magnetized. It occurs to a cer- n extent in all cases, but it should be corrected if it becomes essive. This may be tested by turning the current into the lds, being sure to leave the armature disconnected, and then turn- the shaft with the lever as before. The friction in this case uld not be more than 2 to 4 per cent.

Tests for friction alone should be made at a low speed, because at high speeds the effects of Foucault currents and hysteresis enter and materially increase the apparent friction.

Balance. The perfection of balance of the armature or pulley can be roughly tested by simply running the machine at normal speed and noting if these parts cause any objectionable vibration. Of course, practically every machine produces perceptible vibration when running, but this should not amount to more than a very slight trembling. The balance of a machine can be definitely tested, and the extent of the vibration measured, by suspending the machine or by mounting it on wheels, and running it at full speed. In this case it is better to run the machine as a motor, even though it be actually a generator, in order to avoid the necessity of running it by a belt, which would cause vibration and interfere with the test. If, however, the use of a belt is unavoidable, it should be arranged to run vertically upward or downward so as not to produce any horizontal motion in addition to the vibration of the machine itself. Fig. 40 shows a machine hung up to be tested for balance, and run either as a motor or by the vertical belt indicated by the dotted lines. Any lack of balance will cause the machine to vibrate or swing horizontally, and this motion can be measured on a fixed scale.

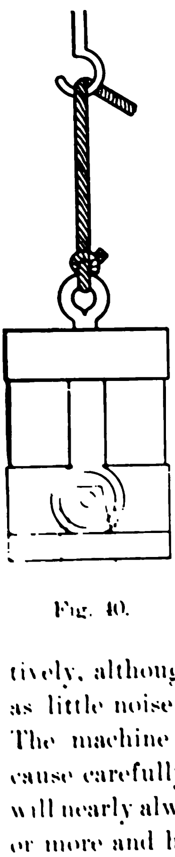

Fig. 40.

Noise. This cannot well be tested quantitatively, although it is very desirable that a machine should make as little noise as possible. Noise is produced by various causes. The machine should be run at full speed, and any noise and its cause carefully noted. A machine—especially the commutator—will nearly always run more quietly after it has been in use a week or more and has worn smooth.

Heating. The proper way to determine the temperature rise in electrical apparatus is by measurements of resistance, before and after operating for a specified time (usually 3 to 4 hours) under rated load.

The rise of temperature is:

$$\theta = (238.1 + t) \left(\frac{(R_t + \theta}{R_t} - 1\right),$$

in which t is the room temperature in degrees Centigrade, R_t the resistance in ohms at room temperature, and $(R_t + \theta)$ the final resistance at a temperature elevation of θ° C. The standard room temperature is 25° C; and if it differs from this, the determined rise should be corrected by $\mp\frac{1}{2}$ per cent for each degree C. For ordinary tests it may be assumed that the resistance of copper increases .4 per cent for each degree C rise in temperature. The allowable rise in temperature for field or armature windings is 50° C, hence their resistance for continuous operation at rated load should not be more than 20 per cent in excess of the room temperature. The heating of commutators, collector rings, and brushes that cannot be measured electrically, is tested by thermometers when the machine is stopped, the permissible rise being 50° C; and for bearings and other parts of machines the limit is 40° C. When a thermometer is applied to a surface it should be covered by a pad of cotton or waste cloth, in a shallow, circular box about $1\frac{1}{2}$ inches in diameter. A large pad tends to accumulate heat. When machines are in operation, or in other cases when it is not convenient to measure resistances, especially for excessive temperatures due to abnormal conditions, thermometers may be used to test all stationary parts; but it should be noted that their indications are usually about 5° C lower than those determined by resistances, because the surface is cooler than the interior. A very simple test of heating is to apply the hand to the armature, etc., and if it can be held there without great discomfort, the temperature is not dangerous. Allowance should always be made, however, for the fact that, on account of its heat conductivity, bare metal feels very much hotter than cotton-covered wires, cloth, etc., at the same actual temperatures; but this apparent difference is much less if the hand is kept on for 10 to 20 seconds.

Sparking at the commutator cannot be accurately measured; but it is very objectionable, and in a machine in good order should be hardly perceptible. In any test one should observe carefully whether the sparking is excessive or not; and if so, to what it is due.

An approach to measurement may be made by starting wit a lightly loaded machine and gradually increasing the load, mea while shifting the rocker-arm and brushes back and forth, an noting at what load it is impossible to find a non-sparking poin In machines the brushes must be shifted to follow the armatu reaction as the load increases; but one should always be able t find a place where sparking ceases, within the rated load. In fac a machine should be able to run with 25 per cent overloa before sparking is serious. If a machine begins to spark at 50 p cent of its load, it is clearly only half as useful as it might b and this may be taken in a sense as a measure of sparking.

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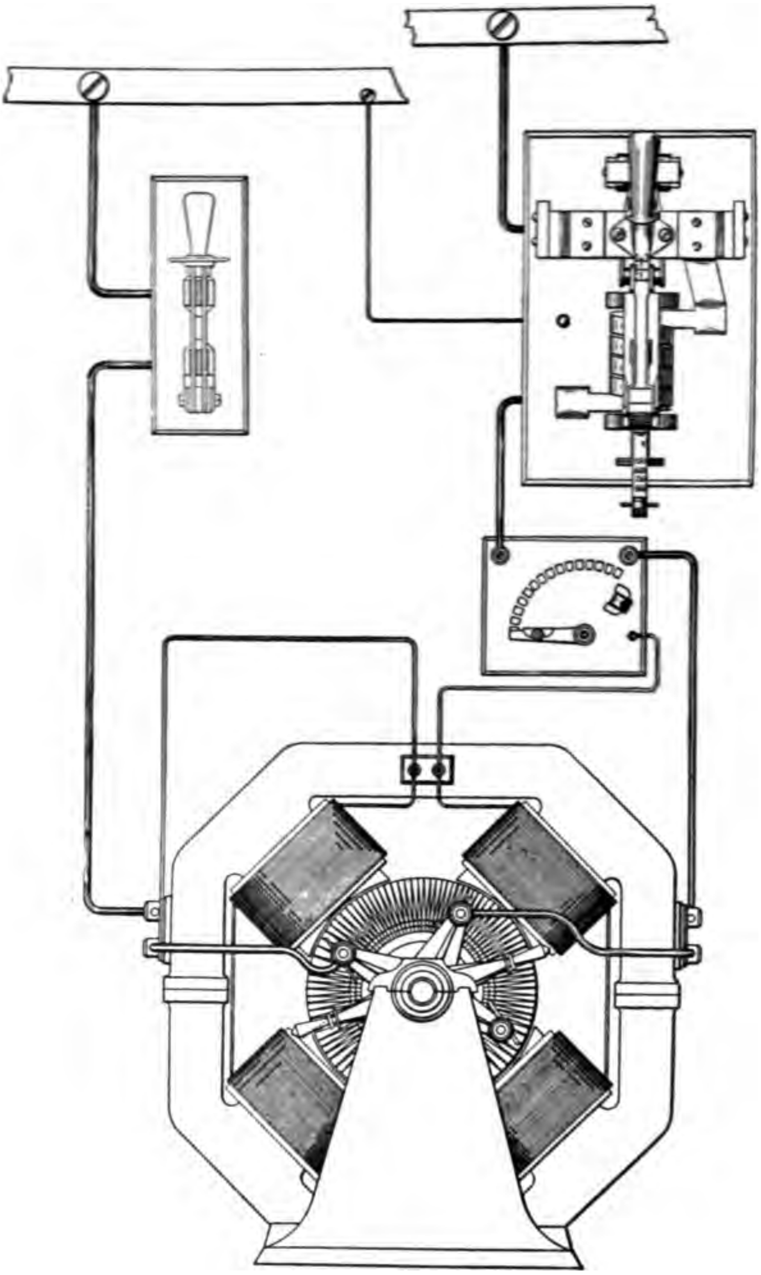

WIRING DIAGRAM.

Connections of Single Pole Overload and no Voltage I-T-E Circuit Breaker.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART II

ELECTRICAL RESISTANCE.

Among the most important tests which it is necessary to make in connection with Dynamo-Electric Machinery are those for resistance.

There are two principal classes of resistance tests that must be made in connection with generators and motors. First, the resistance of the wires or conductors themselves, called the *metallic* resistance; and, second, the resistance of the insulation of the wires, known as the *insulation* resistance. The latter should always be as high as possible, because a low insulation resistance not only allows current to leak, but also causes "burn-outs" and other accidents. Metallic resistance, such, for example, as the resistance of the armature or field coils, is commonly tested either by the Wheatstone bridge or by the "drop" (fall-of-potential) method.

The Wheatstone Bridge is simply a number of branch circuits connected as indicated in Fig. 41. A, B, and C are resistances the values of which are known. X is the resistance which is being measured. G is a galvanometer, S its key, and E is a battery of one or two cells controlled by a key K, all being connected as shown. The resistance C is varied until the galvanometer shows no deflection, when the keys K and S are closed in the order named. If the key S should be closed before K, or at the same moment, the

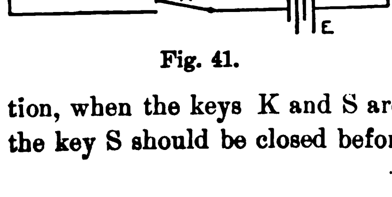

Fig. 41.

inductive effect would produce a pronounced deflection of the galvanometer needle, and thus probably cause confusion. The value of the resistance X is then found by multiplying together resistances C and B, and dividing by A; that is,

$$X = \frac{C \times B}{A}.$$

A very convenient form of this apparatus is what is known as the portable bridge (Fig. 42). This consists of a box containing the three sets of known resistances, A, B, and C, controlled by plugs; also the galvanometer G, and keys K and S, all connected

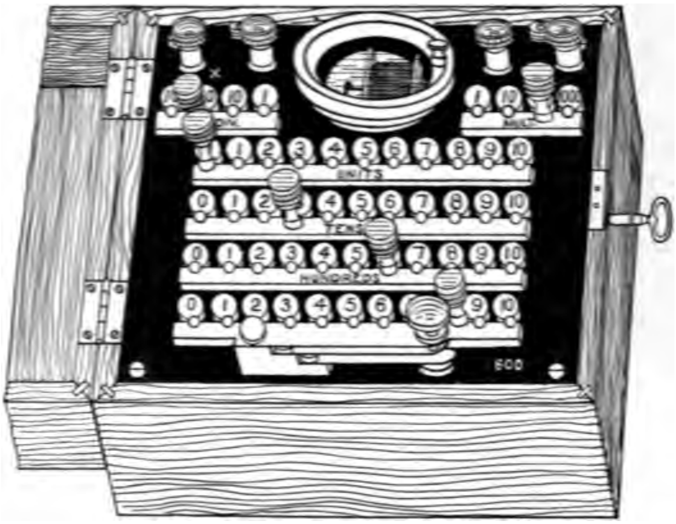

Fig. 42.

in the proper way. In some cases further convenience is secured by including the battery E in the box; but ordinarily this is not done, and it is necessary to connect one or two cells of battery to a pair of binding-posts placed on the box for that purpose. Resistances from $\frac{1}{10}$ ohm to 100,000 ohms can be conveniently and accurately measured by the Wheatstone bridge. Below $\frac{1}{10}$ ohm the resistances of the contacts in the binding-posts and plugs are apt to cause errors, and therefore special bridges provided with mercury contact cups are used. In fact, in measuring any resistance, care should be taken to make the connections clean and tight.

ιe ordinary bridge will not measure above 100,000 ohms, be-
ase, if the resistance in the arm B is 100 ohms, 1 ohm in A, and
)00 ohms in C, then X is 100,000. Sometimes the arms A and
are provided with 1,000-ohm coils in addition to the usual 1-,
'- and 100-ohm coils; or sometimes the arm C contains more
an 1,000 ohms in all; in either case the range will be corre-
ondingly increased.

It should be observed, however, that the use of ratios of 1,000:
or even 100: 1, is not desirable, since they are likely to multiply
y error due to contact resistances, etc. In fact, it is usually bet-
: to have the four resistances not very widely different in value;
at is, no one of them should be more than ten times greater
an any other except when very high or very low resistances are
be measured. The Wheatstone bridge may be used for testing
e resistances of almost any field coils that are found in practice.
ιunt fields for 110-volt machines usually vary from about 100 or
'0 ohms in a 1-H. P. machine to about 5 to 20 ohms in a 100-
. P. machine. If the voltage is higher or lower than 110, these
ɜistances vary as the square of the voltage. Series fields for arc-
·cuit dynamos vary from about 1 to 20 ohms. In measuring
ld resistances with the bridge, care must be taken to wait a con-
lerable time after pressing the battery key, before pressing the
lvanometer key, in order to allow time for the self-induction of
e magnets to disappear.

The bridge may be used also for testing the armature resis-
nce of some machines. But 110-volt shunt machines above 10
. P. usually have resistances less than $\frac{1}{10}$ ohm, which is below
e range of the ordinary bridge, as already stated. For higher
lower voltages the resistance is proportional to the square of the
ltage. Arc machines have armatures of about 1 to 20 ohms
ɜistance, and are therefore easily tested by the bridge.

The Drop (or **Fall-of-Potential**) **Method** is well adapted for
ɔating faults quickly, and for testing the armature resistance of
ɔst generators and motors, or the resistance of contact between
mmutator and brushes, or other resistances which are usually
ly a few hundredths or even thousandths of an ohm. This
nsists in passing a current through the armature and connections
d a known resistance (of, say, $\frac{1}{100}$ ohm), all connected in series,

as represented in Fig. 43. The "drop" or fall of potential in the armature and that in the known resistance are compared by connecting a voltmeter first to the terminals of the known resistance (marked 1 and 2), and then to various other points on the circuit, as indicated by the dotted voltmeter terminals at M, N, O, Q, R, and S, so as to include successively each part to be tested. The deflections in all cases are directly proportional to the resistances included between the points touched by the terminals. The current needed depends upon the resistance of the circuit and the sensitiveness of the voltmeter. A bank of lamps or a liquid resistance is used for limiting the current. Instead of using a known resistance, an ammeter may be inserted in series with the resistance to be tested, the latter being then determined by Ohm's law, *viz.*, If E is the voltmeter deflection, and I represents the amperes flowing, the resistance of the part under test is $R = \frac{E}{I}$

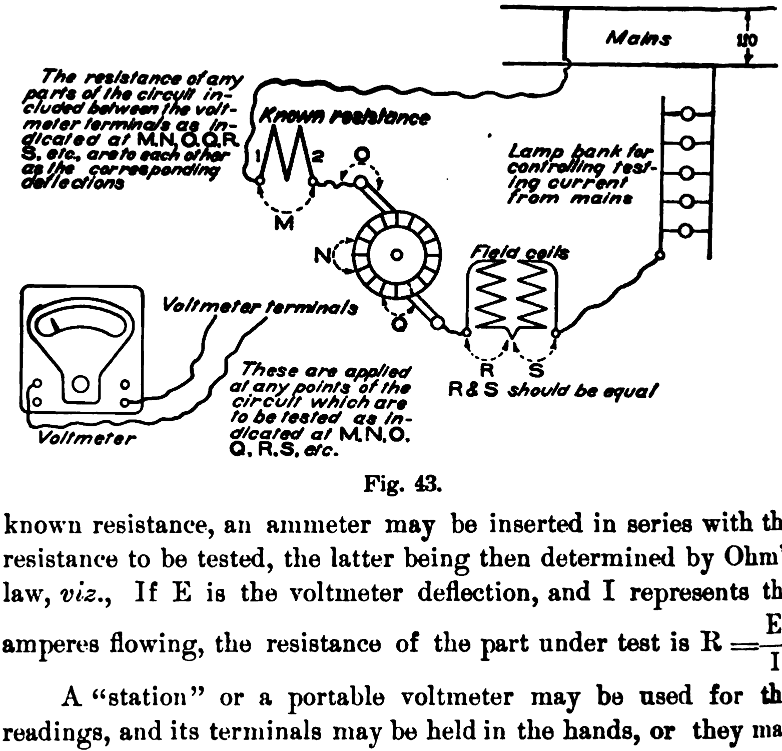
Mains
110
The resistance of any parts of the circuit included between the voltmeter terminals as indicated at M.N.O.Q.R. S. etc., are to each other as the corresponding deflections
Known resistance
1
2
O
M
N
Lamp bank for controlling testing current from mains
Field coils
Voltmeter terminals
Q
These are applied at any points of the circuit which are to be tested as indicated at M.N.O. Q. R.S. etc.
R
S
R & S should be equal
Voltmeter

Fig. 43.

A "station" or a portable voltmeter may be used for the readings, and its terminals may be held in the hands, or they may be conveniently arranged to project from an insulating handle like a two-pronged fork. Usually 10 to 100 amperes and a low-reading voltmeter are needed for low resistances.

It is well to start with a small testing current, and increase it until a good deflection is obtained on the voltmeter. If a current of several amperes cannot be had, a few cells of storage battery or some strong primary battery, such as a Bunsen, bichromate, or plunge battery, can be used with a galvanometer or low-reading voltmeter.

The diagram indicates the testing of a machine with series fields. Shunt fields must be connected directly to the line on account of their high resistance; while the armature can be connected as here shown, without being allowed to revolve.

This drop method of testing is also very useful in locating any fault. The two wires leading from the voltmeter are applied to any two points of the circuit, as indicated by the dotted lines —for instance, to two adjacent commutator segments, or to a brush tip and the commutator; any break or poor contact will be indicated immediately by the deflection being larger than at some other similar part. This shows that the fault is between the two points to which the wires are applied. Thus, by moving these along on the circuit, the exact location of any irregularity, such as a bad contact, short circuit, or extra resistance, can be found.

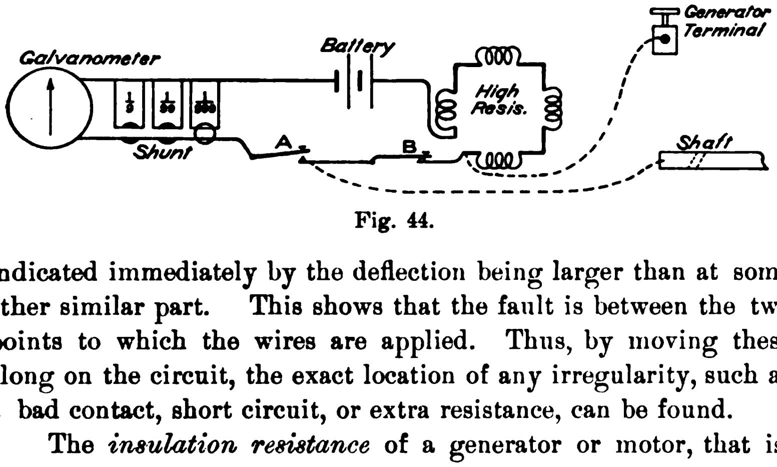

Fig. 44.

The *insulation resistance* of a generator or motor, that is, the resistance between its wires and its frame, should be sufficiently high so that not more than one-millionth of its rated current will pass through it at normal voltage, and it is well to have it still higher. It is therefore beyond the range of ordinary Wheatstone-bridge tests; but two good methods are applicable—the "direct-deflection" and the voltmeter method.

The Direct-Deflection Method is carried out by connecting a sensitive galvanometer, such as a Thomson high-resistance reflecting galvanometer, in series with a known high resistance, usually a 100,000-ohm rheostat, a battery, and keys, as shown in Fig. 44 The galvanometer should be shunted with the $\frac{1}{999}$ coil of the shunt, so that only $\frac{1}{1000}$ of the current passes through the galvanometer, the machine being entirely disconnected. The keys A and B are closed and the steady deflection noted. It is well to use but one cell of the battery at first, and then increase the number if necessary until a considerable deflection is obtained. The circuit is then opened at the key B, and connected by wires to the binding-post or commutator and to the frame or shaft of the machine, as indicated by dotted lines, so that the machine insulation resistance is included directly in the circuit with the galvanometer and battery. The key A is then closed and the deflection noted. Probably there will be little or no deflection, on account of the high insulation resistance; and the shunt is changed to $\frac{1}{99}$, $\frac{1}{9}$, or left out entirely if little deflection is obtained. In changing the shunt, the key should always be open, otherwise the full current is thrown on the galvanometer. The insulation is then calculated by the formula:

$$\text{Insulation resistance} = \frac{D \times R \times S}{d},$$

in which D is the first deflection without the machine being connected, and d the deflection with the machine insulation in the circuit, R the known high resistance, and S the ratio of the shunt. That is, if the shunt is $\frac{1}{999}$ in the first test, and $\frac{1}{9}$ in the second, then S is 100; and if the shunt is out entirely in the second test, S is 1,000. It is safer to leave the high resistance in circuit in the second test, to protect the galvanometer in case the insulation resistance is low. Therefore this resistance must be subtracted from the result to obtain the insulation of the machine itself.

By the above method it is possible to measure 100 megohms or even more. The wires and connections should be carefully arranged to avoid any possibility of contact or leakage, which would spoil the test. If no deflection is obtained, place one finger on the frame and one on the binding-post of the machine, which makes enough leakage to affect the galvanometer and show that the connections are right, thus proving that any poor insulation will be indicated if it exists.

The Voltmeter Test for Insulation Resistance requires a sensitive high-resistance voltmeter, such as the Weston. Take, for example, the 150-volt instrument, Fig. 45, which usually has about 15,000 ohms resistance. (A certificate of the exact resistance is pasted inside each case.) Apply it to some circuit or battery, and measure the voltage. This should be as high as possible—say, 100 volts. The insulation resistance of the machine is then connected into the circuit, as indicated in Fig. 46. The deflection of the voltmeter is less than before, in proportion to the value of the insulation resistance.

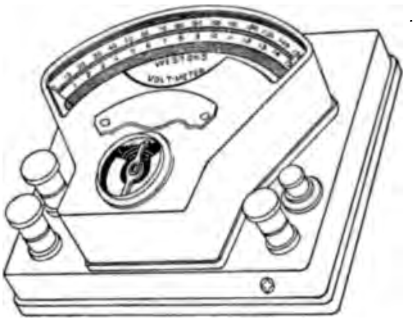

Fig. 45.

The insulation is then found by the equation:

$$\text{Insulation resistance} = \frac{D \times R}{d} - R,$$

in which D is the first and d the second deflection, and R the resistance of the voltmeter. If the circuit is 100 volts, D is 100; and if d, the deflection through the insulation resistance of the machine, is 1 division, the insulation is 1,485,000 ohms. Permanent marks indicating amounts of insulation may be put on the voltmeter scale. When making measurements, the voltage should be the same as that employed in preparing this scale (say, 115 volts). To calculate the scale use this formula:

$$d = \frac{115\ R}{X + R},$$

in which X is the insulation resistance (1 megohm, ½ megohm, etc.), and d is the number of volts, opposite which the corresponding graduation is to be placed to form the new scale. This method does not test very high resistances; but if little or no deflection is obtained through the insulation resistance, it shows that the latter is at least several megohms — which is high enough for most practical purposes.

The ordinary magneto-electric bell may be used to test insulation by simply connecting one terminal to the binding-post of the machine, and the other to the frame or shaft.

A magneto bell is rated to ring from 10,000 to 30,000 ohms; and if it does not ring, it shows that the insulation is more than that amount. This limit is altogether too low for proper insulation in any case; and therefore this test is rough, and really shows only whether or not the insulation is very poor or the machine actually grounded.

The magneto is also used for "continuity" tests, to determine whether a circuit is complete, by simply connecting the two terminals of the magneto to those of the circuit. If the bell can be rung, it shows that the circuit is complete; if not, it indicates a break. An ordinary electric bell and cell of battery can be used in place of the magneto.

The insulation of a machine should always be tested for disruptive strength, with a current of at least double the normal working pressure, to see if it will "break down" or be punctured by the current. A transformer motor-dynamo wound to give high voltage is convenient for this.

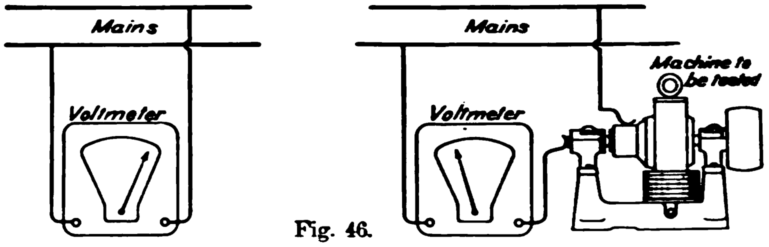

Fig. 46.

Tests of the resistances of generators or motors should properly be made when the machines are as warm as they get when running continuously at full load. This increases the resistance of conductors and decreases the insulation resistance, but it gives the actual working values.

Voltage. Instruments for measuring voltage (known as voltmeters) are in nearly all cases galvanometers of practically constant resistance. Through them flow currents which are directly proportional to the impressed voltages. A pointer connected to the moving part deflects over a graduated scale. A voltmeter should have as high a resistance as possible—at least several thousand ohms—in order not to take too much current, which might lower its reading on high-resistance circuit or consume too much power. It should not be affected by the magnetism of a generator or motor at any distance over a few feet.

The voltage of any machine or circuit is tested by merely connecting the two binding-posts or terminals of the voltmeter to the two terminals or conductors of the machine or circuit. To get the external voltage of a generator or motor, the voltmeter is usually applied to the two main binding-posts or brushes of the machine. This external voltage is what a generator supplies to the circuit. It is also called the pole difference of potential or terminal voltage, and is the actual figure upon which calculations of the efficiency, capacity, etc., of any machine are based.

A generator for constant-potential circuits should, of course, give as nearly as possible a constant voltage. A plain shunt machine usually falls from 5 to 15 per cent in voltage when its current is varied from nothing to full load. This is due to the I R drop caused by the resistance of the armature circuit, which in turn weakens the field current and magnetism; armature reaction usually occurs also, and still further lowers the external voltage. This variation is undesirable, and is usually avoided by regulating the field magnetism (varying the resistance in the field circuit) or by the use of compound-wound generators. A compound-wound dynamo should not fall appreciably from no load to full load; in fact, if it is "over-compounded" it should rise 5 per cent or more in voltage to make up for loss on the wiring.

The voltage of a constant-current generator is not important. The current should be carefully measured by an ammeter, but little attention is paid to the voltage in practical working; in fact, it changes constantly with variations in the load. But it is necessary, of course, to measure it in making efficiency or other exact tests.

A simple and fairly accurate method of measuring voltage is by means of ordinary incandescent lamps. A little practice enables one to tell whether a lamp has its proper voltage and brightness. In this way it is easy to tell if the voltage is even one or two per cent above or below the normal point. Voltages less than the ordinary can be tested by using low-voltage lamps or by estimating the brightness of high-voltage lamps. For example, a lamp begins to show a very dull red at one-third and a bright red at one-half its full voltage. Voltages higher than that of one lamp can be tested by using lamps in series. Thus 1,000 volts can be measured by using 10 lamps in series, and so on.

Current. This is measured by an ammeter (Fig. 47), which is usually cheaper than a voltmeter because it contains a comparatively small amount of wire. In testing the current of a generator or motor, it is necessary only to connect an ammeter, of the proper range, in series with the machine to be tested, so that the whole current passes through the instrument or its shunt. To test the current in the armature or the field alone, the ammeter is connected in series with the particular part. To avoid mistakes in the case of a shunt-wound generator, it is well to open the external circuit entirely in testing the current used in the field coils; for the same reason the brushes of a shunt motor should be raised before testing the current taken by the field.* In a constant-current or series-wound dynamo, the same current flows through all parts of the machine and the circuit; consequently the measurement of current is very simple.

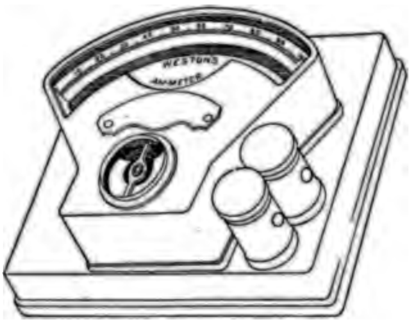

Fig. 47.

If an ammeter cannot be had, current can be measured by inserting a known resistance in the circuit and measuring the difference of potential between its ends. The volts thus indicated, divided by the resistance in ohms, gives the number of amperes flowing. If a known resistance is not at hand, the resistance of a part of the wire forming the circuit can be obtained from its diameter measured with a screw caliper or a wire gauge, by referring to any of the tables of resistances of wires; or the resistance can be measured by a Wheatstone bridge (Fig. 42), or by putting an ammeter, when one can be spared, into the circuit, while the voltmeter is connected. The volts divided by the amperes gives the resistance in ohms between the points to which the voltmeter is connected. Two connections can be attached permanently to two points on the circuit, and an ammeter tem-

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* These instructions are to be followed when only one ammeter is to be had; otherwise one could be placed in the field circuit, and another in the circuit from the starting box to the independent armature terminal.

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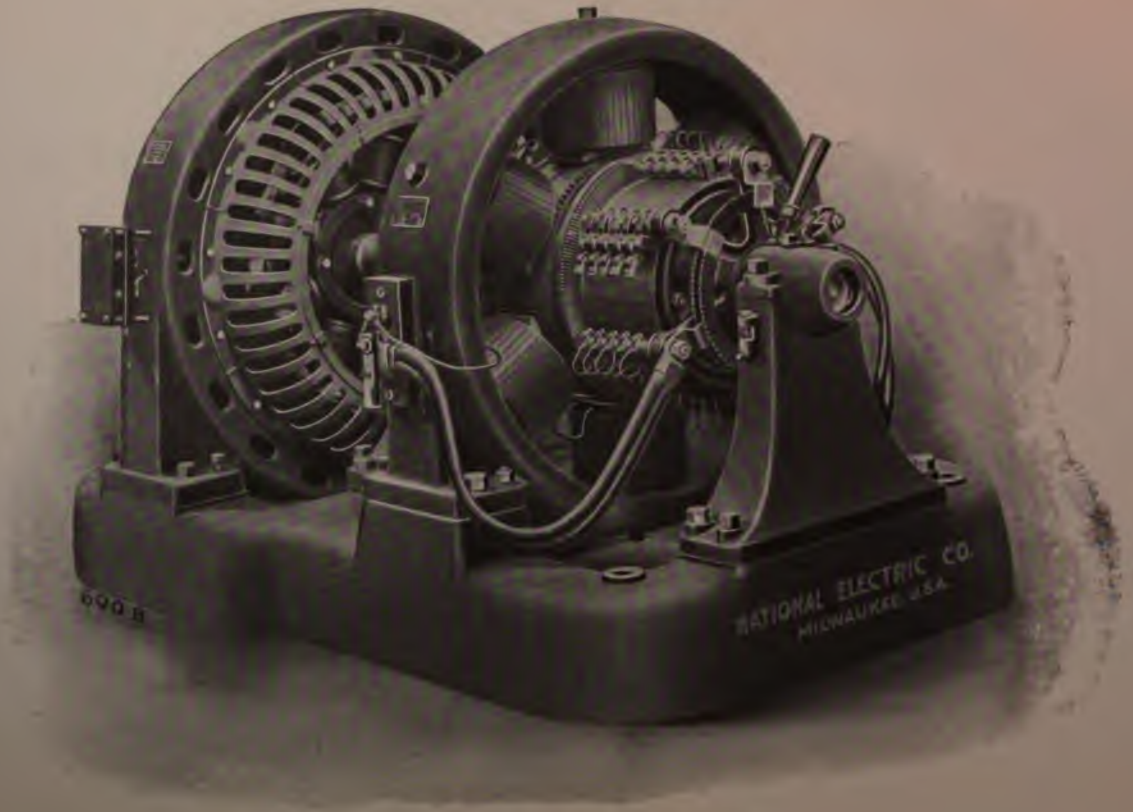

"NATIONAL" MOTOR-EXCITER SET.

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porarily inserted, and for every reading of the ammeter the corresponding reading of the voltmeter attached to these connections may be noted. Then, by keeping a list of these readings, the amperes can be found at any future time, by connecting the voltmeter to the two permanent contacts. This preliminary use of the ammeter amounts to measuring the resistance between the two contacts, and allows for the increase of resistance when the current and heating increase. In any case it is convenient to use a length of wire, or a distance between contacts, which will give an even amount of resistance, say, 1-10 or 1-100 ohm. And, as with large current the resistance will be fractional, care must be taken to avoid errors in multiplying, etc.

In testing the output of a generator, it is often quite a problem to dispose of the current produced. A bank of lamps, for example, to use the whole current generated by a dynamo of 110 volts and 1,000 amperes, would be very expensive. A sufficient number of resistance-boxes for the purpose would also be very costly. The best way is to drive the generator by a motor, and connect it up in parallel with the line. In this way most of the power is returned instead of being wasted. If a motor cannot be had, the simplest and cheapest way to consume a large current is to place two plates of iron in a common tub or trough filled with a weak solution of carbonate of soda (common washing soda), which is better than almost any other solution because it neither gives off fumes nor eats the electrodes. The main conductors are connected to the two plates, respectively, and the current passes through the solution. The resistance and current are regulated by varying the distance between the plates, the depth they are immersed in the liquid, and the strength of the solution. The energy may be suf-

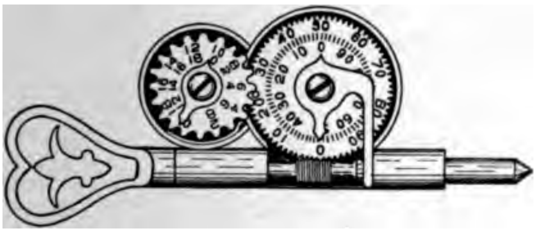

Fig. 48.

ficient to boil the liquid, but this does no harm. Three to ten amperes per square inch of active surface of plate may be allowed.

Speed. This is usually measured by the well-known **speed counter** (Fig. 48), consisting of a small spindle which turns a wheel one tooth each time it revolves. The point of the spindle is held against the center of the shaft of the generator or motor for a certain time, say, one minute or one-half minute, and the number of revolutions is read off from the position of the wheel.

Another instrument for testing the number of revolutions per minute is the **tachometer.** The stationary form of this instrument is shown in Fig. 49. It must be belted by a string, tape, or light leather belt to the machine the speed of which is to be tested. If the sizes of the pulleys are not the same, their speeds are inversely proportional to their diameters. The portable form of this instrument (Fig. 50) is applied directly to the end of the shaft of the machine, like the speed counter. The tip can be slipped upon either one of the three spindles, which are geared together, according as the speed is near 500, 1,000, or 2,000 revolutions. These instruments possess the great advantage over the speed counter that they instantly point on the dial to the proper speed, and they do not require to be timed for a certain period.

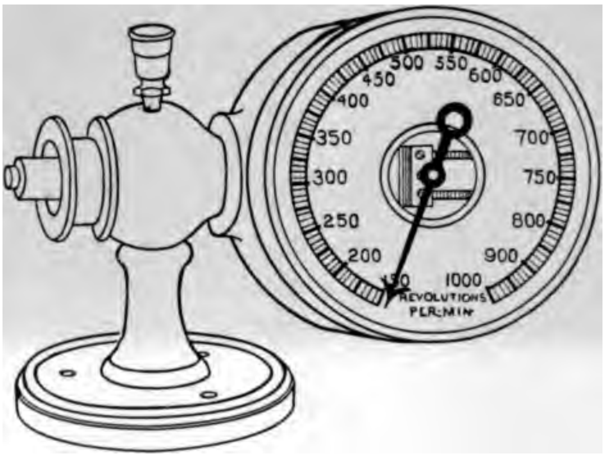

Fig. 49.

A simple way to test the speed in revolutions per minute is to make a large black or white mark on the belt of a machine, and note how many times the mark passes per minute ; the length of the belt divided by the circumference of the pulley gives the number of revolutions of the pulley for each time the mark passes. The number of revolutions of the pulley to one of the belt can also be easily determined by slowly turning the pulley or pulling the belt until the latter makes one complete trip around, at the same time counting the revolutions of the pulley. If the machine has no belt, it can be supplied with one temporarily for the purpose of the test, a piece of tape with a knot or an ink mark being sufficient. Care should be taken in all these tests of speed with belts not to allow any slip ; for example, in the case of the tape belt just referred to, this belt should pass around the pulley of the machine and some light wheel of wood or metal which turns so easily as not to cause any slip of the belt on the pulley of the machine.

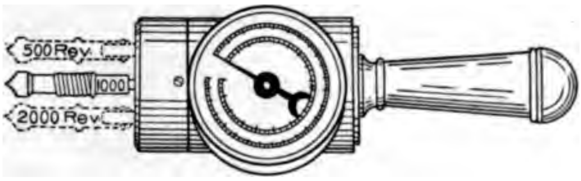

Fig. 50.

Torque or **Pull** is measured in the case of a motor by the use of a Prony brake. This consists of a lever LL of wood, clamped on the pulley of the machine to be tested, as indicated in Fig 51. The pressure of the screws SS is then adjusted by the wing-nuts until the friction of the clamp on the pulley is sufficient to cause the motor to take a given current, and the speed is then noted. Usually, the maximum torque or pull is the most important to test; and this is obtained in the case of a constant-potential motor by tightening the screws SS until the motor draws its full current as indicated by an ammeter. What the full current should be, is usually marked on the name-plate ; if not, it may be assumed to be about 8 amperes per H. P. for 110-volt motors, 4 amperes per H. P. for 220-volt, and 1 3-4 amperes per H. P. for 500-volt motors. If the machine is rated in kilowatts, the full current in amperes can be found by multiplying by 1,000 and dividing by the voltage of the machine. The torque or pull is measured by known weights, or more conveniently by a spring balance P. If desired, the test may also be made at three-quarters, one-half, or any other fraction of the full current.

The torque or pull in pounds which should be obtained, can also be calculated from the power at which the machine is rated, by the formula ;

$$\text{Torque} = \frac{\text{H. P.} \times 33{,}000}{6.28 \times \text{S}},$$

in which H. P. is the horse-power of the machine at full load, and S is the speed of the machine in revolutions per minute at full load. Torque is given at unit radius, commonly pounds at one foot. The pull at any other radius is converted into torque by multiplying by the radius; 1, 2, and 4 ft. are convenient radii or lengths of lever for measuring pull. One H. P. produced at a speed of 1,000 revolutions requires a pull of 5.25 pounds at end of 1-foot lever; at 500 revolutions, twice as much; at 2,000 revolutions half as much; and so on. If the lever is 4 feet, the pull is one-fourth as much, etc.

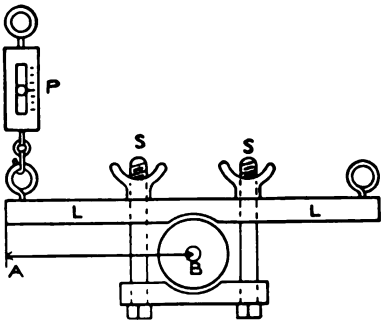

Fig. 51.

The Torque of a Generator, that is, the power required to drive it, is very conveniently determined by operating it as a motor, and testing it by the Prony brake as described above, the torque of a generator being practically equal to that of a motor under similar conditions.

Power. The electrical power of a generator or motor is found by testing the voltage and current at the terminals of the machine, as already described, and multiplying the two together, which gives the electrical power of the machine in watts.* Watts are converted into horse-power by dividing by 746, and into kilowatts by dividing by 1,000.

The mechanical power of a generator or motor, that is, the power required for or developed by it, is found by multiplying its pull by its speed and by the circumference on which the pull is measured, and dividing by 33,000. That is,

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*In testing an alternating-current machine, a wattmeter should be employed instead of a voltmeter and an ammeter, as explained later.

$$\text{Horse-power} = \frac{\text{P} \times \text{S} \times 6.28 \times \text{R}}{33{,}000},$$

in which P is the pull in pounds, S the speed in revolutions per minute, and R the radius in feet at which P is measured.

Efficiency. This is determined in the case of a generator by dividing the electrical power generated by it by the mechanical power required to drive it; that is,

$$\text{Efficiency of generator} = \frac{\text{Electrical power}}{\text{Mechanical power}}.$$

The efficiency of a motor is the mechanical power developed by it, divided by the electrical power supplied to it; that is,

$$\text{Efficiency of motor} = \frac{\text{Mechanical power}}{\text{Electrical power}}.$$

These are the **actual** or **commercial efficiencies** of these machines, and should be at least 90 per cent at rated load in machines of 10 H. P. and over.

The so-called "electrical efficiency" is misleading and of little practical importance, and should not be considered in commercial work. The mechanical and electrical power in the above equations are determined as already explained.

It is usually more convenient to test the efficiency of a generator by testing it as a motor with a Prony brake. But the efficiency of a generator may be determined very easily by driving it with a calibrated electric motor, that is, one in which the power developed for any given number of volts and amperes consumed is known. Then it is only necessary to measure the watts supplied by the generator when the motor is running at a certain power, and the efficiency of the generator is *the watts ÷ the known power.*

Another method is to employ two identical machines, one used as a motor driving the other as a generator. The shafts of the two machines should be directly connected by some form of coupling; a belt may be used, but its friction would cause a

small loss. The watts produced by the generator, divided by the watts consumed by the motor, is the combined efficiency of the two machines; and the efficiency of each is the square root of that fraction. For example, if the combined efficiency is .81, then that of each machine is .90, since .90 × .90 = .81. This assumes that the two efficiencies are equal, which is sufficiently correct if the machines are exactly alike. The current from the generator may be used to help feed the motor, and then only the difference in current need be supplied. This latter current represents the inefficiency or losses from friction, etc., in both machines.

To test in this way, connect both machines in parallel with the source of current; couple or belt them together; and then weaken the field, or shift the brushes of the machine which is to be used as a motor, so that it will speed up and drive the other as a dynamo, or cause it to drive the other by putting a large pulley on it. In this way the motor will consume current from the circuit while the generator yields current to the circuit. Both currents are measured and the efficiencies calculated.

The efficiency of a motor-generator or ordinary converter is very easily determined by simply measuring the input and output in watts (by wattmeters or by ammeters and voltmeters for direct currents), and dividing the latter by the former.

These electrical methods of testing are preferable to mechanical, for the reason that the volts and amperes can be easily and accurately measured, and their product gives the power in watts.* Mechanical measurements of power by dynamometer or other means are difficult, and usually not very accurate.

Separation of Losses. The total losses in a generator or motor, except that caused by the electrical resistance of the armature when carrying the full current, can be closely determined at once by noting the current required to run the machine free as a motor. In a machine of 90 per cent efficiency, this should not amount to more than about 8 per cent of the current required to give rated power. Consequently the easiest way to test a machine is to run it as a motor without load.

The various losses of power that occur in a generator or motor may be determined and separated from each other as follows:

*** When alternating-current machinery is being tested use wattmeters.**

Take a generator, for example, and drive it with another machine used as a motor in the manner described for testing friction. The motor should previously be calibrated, that is, tested to determine the exact mechanical power it develops for each amount of electrical power in watts supplied to it, as described for testing efficiency. A simple, shunt-wound motor on a constant-potential circuit is best suited to the purpose. The generator is first driven at normal speed with no field magnetism and with the brushes lifted; then the actual power developed by the motor equals the power lost in the generator by the friction of bearings and belt. The brushes are then adjusted in contact with the commutator, with the usual pressure. The increase in the power of the motor is equal to the brush friction.

Finally, excite the field magnet to full strength, and the increase in the power exerted by the motor is equal to the combined losses due to the Foucault or eddy currents and hysteresis in the iron core of the armature, provided there is no considerable side pull on the armature. The power wasted in Foucault currents varies as the square of the speed, while the hysteretic loss is only directly proportional to speed; hence the two may be separated by testing the machine at different speeds.

For example, let us call x and y the losses due to hysteresis and Foucault currents, respectively, at full speed; A the power consumed by both at full speed; and B the power consumed at half speed. Then $A = x + y$, and $B = \frac{x}{2} + \frac{y}{4}$; hence, by eliminating x, we have $y = 2A - 4B$. That is the Foucault loss is twice the power consumed by both at full speed minus four times the power consumed by both at half speed. The hysteresis loss $= A - y$. If eddy currents are developed in the copper conductors of the armature, they will increase the apparent Foucault loss as determined by the above test, since they also vary as the square of the speed. The power wasted by eddy currents might be found by testing the armature without any conductors upon it. This could be done only before the armature is wound or by unwinding it, neither of which is practicable except in the place where it is made. Ordinarily, however, eddy currents in the conductors do not amount to much unless they are very large, and even then the use of stranded conductors or conductors embedded in slots in the iron core largely overcomes the trouble.

Friction of the air might also increase the apparent Foucault loss; but it usually causes only a very small loss, and is almost impossible to separate except by running the machine in a vacuum, which is, of course, impracticable. The other losses are quite easily measured and separated, as follows :

The number of watts used in the field can be measured by a voltmeter and ammeter, or it can be calculated by the formula: $\text{Watts} = \frac{E^2}{R} = I^2R = EI$, in which E is the voltage, R the resistance, and I the current. It is sufficient if any of these two quantities are known. The loss in the armature conductors, due to ohmic resistance is found by multiplying the square of the current in the armature at full load by the armature resistance; in fact, this is usually called the " I^2R loss." This should not be more than 1 to 3 per cent in a constant-potential generator or motor, whether it be alternating-or direct-current. The sum of all the losses make up the difference between the total power consumed by the machine and the useful power that it develops.

The ordinary values of the various losses in a good generator or motor of 25 H. P. are approximately as follows :

Useful power developed	about 92 per cent.
Used in magnetizing field	about 1 to 2 "
Loss in armature resistance (I^2R)	" 1 to 2 "
Friction of bearings	about 2 "
Friction of brushes	" ½ "
Friction of air	" ½ "
Hysteresis in armature core	" 1½ "
Foucault currents in armature core	" 1½ "

Measurement of Power in A. C. Circuits. In circuits carrying alternating currents and having some inductive load either in the form of motors or arc lamps or a partly loaded transformer, etc., the ordinary method of determining the power, by voltmeter and ammeter measurements, is not applicable, as the current is seldom in phase with the E. M. F., and therefore the product *volts* × *amperes* is not the true power.

There are several means for determining the true power of an A. C. circuit, the simplest being an indicating wattmeter. A wattmeter is an electro-dynamometer provided with two coils, a fixed one of coarse wire, the other movable and of fine wire. This movable coil is connected in series with a large non-inductive resistance, so that the time-constant of the fine-wire circuit is extremely small; and hence its impedance is practically equal to its resistance; the current in, and resulting field of, the fine-wire coil will under these conditions be practically in phase with the potential difference across its terminals. The field produced by the coarse-wire coil is directly proportional to the current flowing through it at any instant. Hence, the couple acting on the fine-wire coil is proportional at a given instant to the product of these fields; so that the reading of the instrument, which depends on the mean value of the couple, will be proportional to the mean power, and, by providing the instrument with the proper scale, it can be made to read directly in watts.

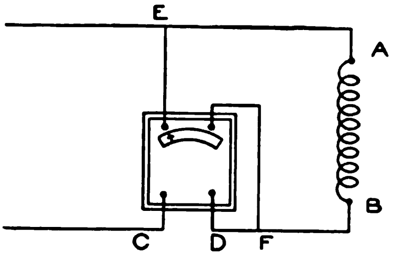

Fig. 52.

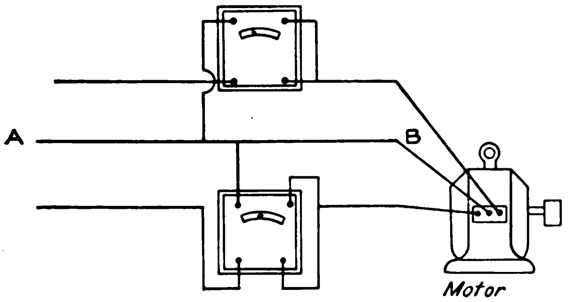

Fig. 53.

In Fig. 52, A B represents an inductive load—say, a single-phase motor—of which the power input is to be determined; C D the terminals of the thick-wire coil (current-coil) of the wattmeter; and E F the pressure-coil terminals. When connected as above indicated, the wattmeter indicates directly the power in watts supplied. In the case of a two-phase system, where the two circuits are independent, the power may be measured by placing a watt-

meter in each phase, as shown in Fig. 52, and adding the two readings. If the motor be connected up as shown in Fig. 53,* where A B forms a common return, the wattmeters are placed as indicated, *care being taken to place the current-coils in the out-*

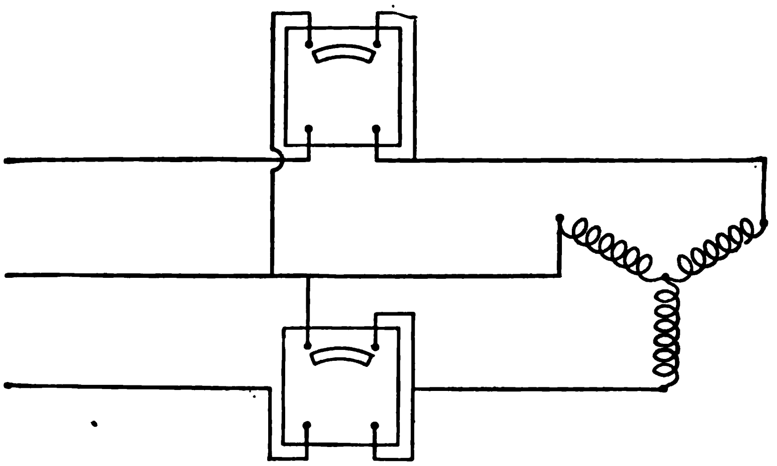

Fig. 54*a*.

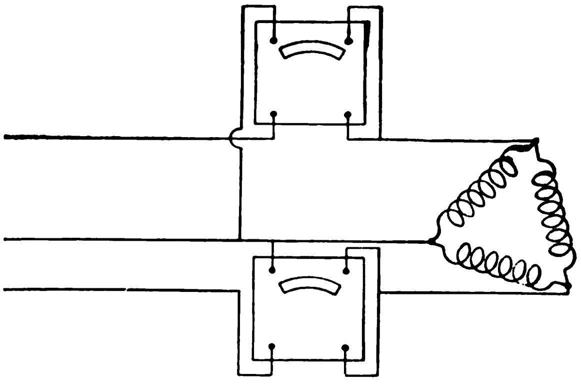

Fig. 54*b*.

side mains; and the power supplied is equal to the sum of the two wattmeter readings.

The power of a balanced or unbalanced three-phase system can be determined by the use of two wattmeters connected as wn in Fig. 54, *a* and *b*. The current-carrying coils are placed series with two of the wires, and the pressure-coil respectively nected between these two mains and the third wire. The *algebraic* sum of these two wattmeter readings gives the true power supplied. When the power factor of the system is less than .5, one of the wattmeters will read negatively It is sometimes difficult to determine whether the smaller readings are negative or not. If in doubt, give the wattmeter a separate load of incandescent lamps, and make the connections :h that both instruments deflect properly; then reconnect them the load to be measured. If the terminals of one instrument re to be reversed, the readings of that wattmeter are negative.

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* This form of connection is possible only when the generator has two independent windings, one for each phase.

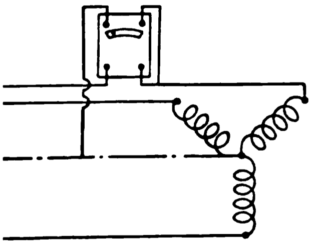

Fig. 55.

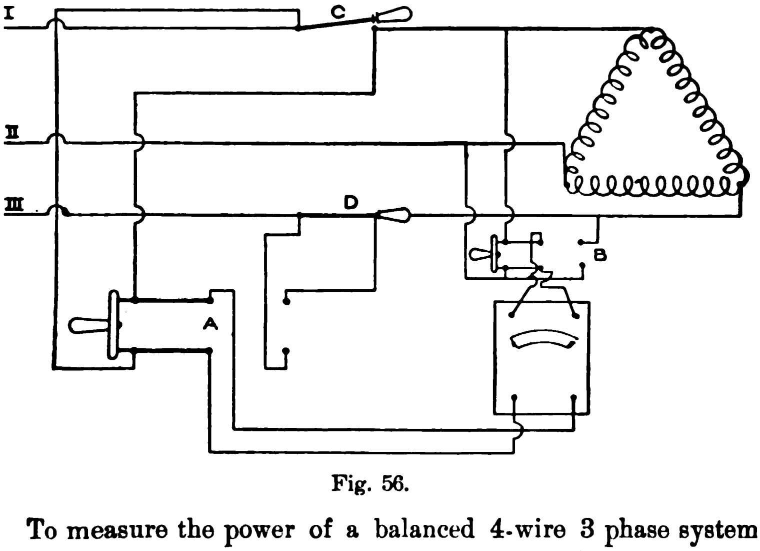

Fig. 56.

To measure the power of a balanced 4-wire 3 phase system,
wattmeter may be connected as shown in Fig. 55, and the ttmeter reading multiplied by 3. Usually, however, a 4-wire hase system is unbalanced; and to determine the power suped under this condition, three wattmeters should be employed, for each phase, the power supplied being equal to the algebraum of all three readings.

It is obvious that in any of the above instances one wattmeter could be employed, provided the necessary switches are furnished. Assuming, for example, the 3-phase 3-wire case, one wattmeter would require switch connections as shown in Fig. 56. A is a double-pole switch, which, when thrown to the left, places the current-coil of the wattmeter in series with the conductor of No. I, and, when thrown to the right, places it in series with No. III. Similarly, switch B changes the pressure terminals from between I and II to III and II; while switches C and D are short-circuiting switches, one of which is closed previous to removing the current-coil from one phase to the other, and the other one opened after the coil is in position as indicated.

LOCALIZATION AND REMEDY OF TROUBLES.

The promptness and ease with which any accident or difficulty with electrical machinery can be dealt with, will always have much to do with the success of a plant. The following list of troubles, symptoms, and remedies for the various types and sizes of dynamos and motors in common use, has been prepared to facilitate the detection and elimination of such difficulties.

It is evident that the subject is somewhat complicated and difficult to handle in a general way, since so much depends upon the particular conditions in any given case, every one of which must be included in the table in such a way as to distinguish it from all others Nevertheless, it is remarkable how much can be covered by a systematic statement of the matter, and nearly all cases of trouble most likely to occur are covered by the table, so that the detection and remedy of the defect will result from a proper application of the rules given.

It frequently happens that a trifling oversight, such as allowing a wire to slip out of a binding-post, will cause as much annoyance and delay in the use of electrical machinery as the most serious accident. Other troubles, equally simple but not so easily detected, are of frequent occurrence.

The rules are made, as far as possible, self-explanatory; but a statement of the general plan followed and its most important features will facilitate the understanding and use of the table.

USE OF THE TABLE OF TROUBLES.

In the use of this table, the principal object should be to eparate clearly the various causes and effects from one another. A careful and thorough examination should first be made; and, s far as possible, one should be perfectly sure of the facts, rather han attempt to guess what they are and jump at conclusions. Of ourse, general precautions and preventive measures should be aken before any troubles occur, if possible, rather than to wait ntil a difficulty has arisen. For example, one should see that he machine is not overloaded or running at too high voltage, and hould make sure that the oil-cups are not empty. Neglect and arelessness with any machine are usually and deservedly followed y accidents of some sort. It is usually wise to stop the machine when any trouble manifests itself, even though it does ot seem to be very serious. It is often practically impossible to shut down; but even then, spare apparatus should be eady. The continued use of defective machinery is a common ut very objectionable practice.

The general plan of the table is to divide all troubles that ay occur to generators or motors, into ten classes, the headings f which are the ten most important and obvious bad effects produced in these machines, *viz.:*

I. Sparking at Commutator.
II. Heating of Commutator and Brushes.
III. Heating of Armature.
IV. Heating of Field Magnets.
V. Heating of Bearings.
VI. Noisy Operation.
VII. Speed not right.
VIII. Motor stops or fails to start.
IX. Dynamo fails to generate.
X. Voltage not right.

Any one of these general effects is evident, even to the casual bserver, and still more so to any person making a careful examination; hence nine-tenths of the possible cases can be eliminated immediately.

The next step is to find out which particular one of the eight ten causes in this class is responsible for the trouble. This uires more careful examination, but nevertheless can be done h comparative ease in most cases. One cause may produce two effects, and, *vice versa*, one effect may be produced by two causes; but the table is arranged to cover this fact as far as possible. In a complicated or difficult case it is well to read through the entire table and note what causes can possibly apply. Generally there will not be more than two or three; and the particular one can be picked out by following the directions, which show how each case may be distinguished from any other.

I. SPARKING AT THE COMMUTATOR.

This is one of the most common of troubles, being often quite serious because it burns and cuts the commutator and brushes, at the same time producing heat that may spread to and injure the armature or bearings. Any machine having a commutator is liable to it, including practically all direct-current and some alternating-current machines. The latter usually have continuous collecting rings not likely to spark; but self-exciting or composite-wound alternators, rotary converters, and some alternating-current motors have supplementary direct-current commutators. A certain amount of sparking occurs normally in most constant-current dynamos for arc lighting, where it is not very objectionable, since the machines are designed to stand it and the current is small.

CAUSE 1. **Armature carrying too much current,** due to (*a*) overload (for example, too many lamps fed by dynamo, or too much mechanical work done by motor; a short circuit, leak, or ground on the line may also have the effect of overloading a dynamo); (*b*) excessive voltage on a constant-potential circuit, or excessive amperes on a constant-current circuit. In the case of a motor, any friction, such as armature striking pole pieces, or a shaft not turning freely, may have the same effect as overload.

SYMPTOM. Whole armature becomes overheated, and belt (if any) becomes very tight on tension side, sometimes squeaking because of slipping on pulley. Overload due to friction is detected by stopping the machine, and then turning it slowly by hand. (See V and VI, 2.)

REMEDY. (*a*) Reduce the load; or eliminate the short circuit, leak, or ground on the line; (*b*) decrease size of driving pulley, or (*c*) increase size of driven pulley; (*d*) decrease magnetic strength of field in the case of a dynamo, or increase it in the case of a motor. If excess of current cannot satisfactorily be overcome in any of the above ways, it will be necessary to change the machine or its winding. Overload due to friction is eliminated as described under V and VI, 2.

If the starting or regulating rheostat of a motor has too little resistance, it will cause the motor to start too suddenly and to spark badly at first. The only remedy is more resistance in the box.

Cause 2, **Brushes not set at the neutral point.**

Symptom. Sparking varied by shifting the brushes with rocker-arm.

Remedy. Carefully shift brushes backwards or forwards until sparking is reduced to a minimum. This can be done by simply moving the rocker-arm. If only slightly out of position, heating alone may result, without disarrangement being bad enough to show sparking. If the brushes are not exactly opposite in a bipolar, 90° apart in a four-pole machine, and so on, they should be made so, the proper points of contact being determined by counting the commutator-bars or by careful measurement.

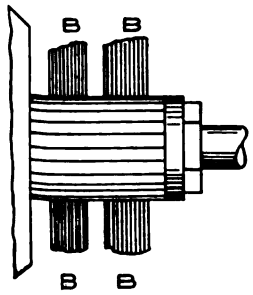

Fig. 57.

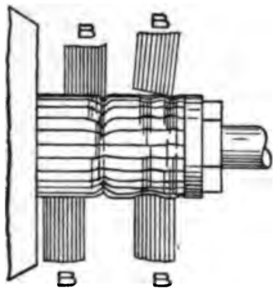

Fig. 58.

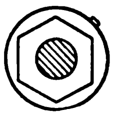

Fig. 59.

The usual position for brushes is opposite the spaces between the pole pieces, but in some machines they must be set in line with centers of pole pieces or at some other point. If the brushes are set exactly wrong, this will cause a dynamo to fail to generate, and a motor to fail to start, and will blow the fuse or open the circuit-breaker. (See IX, 6.)

Cause 3. **Commutator rough, eccentric, or has one or more "high bars"** projecting beyond the others, or one or more

flat bars, commonly called **flats,** or **projecting mica,** any one of which causes the brushes to vibrate or to be actually thrown out of contact with the commutator (Figs. 58 and 59). Hard mica between the bars, which does not wear as rapidly as the copper, will prevent good contact or throw brushes off.

SYMPTOM. Note whether there is a glaze or polish on the commutator, which shows smooth working; touch revolving commutator with tip of finger nail, and the least roughness is perceptible; or feel brushes to see if there is any jar. If the machine runs at high voltage (over 250), the commutator or brushes should be touched with a stick or quill to avoid danger of shock. In the case of an eccentric commutator, careful examination shows a rise and fall of the brush when the commutator turns slowly, or a chattering of brush when it is running fast. Sometimes, by sighting in line with brush contact, one can see daylight between commutator and brush, owing to brush jumping up and down.

REMEDY. Smooth the commutator with a fine file or fine sandpaper, which should be applied on a block of wood that exactly fits the commutator (being careful to remove any sand remaining afterward; and *never use emery*). If commutator is very rough or eccentric, the armature should be taken out and put in a lathe, and the commutator turned off. Large machines often have a slide-rest attachment (Fig. 60), so that the commutator can be turned off without removing the armature. This is clasped on the pillow-block after removing the rocker-arm.

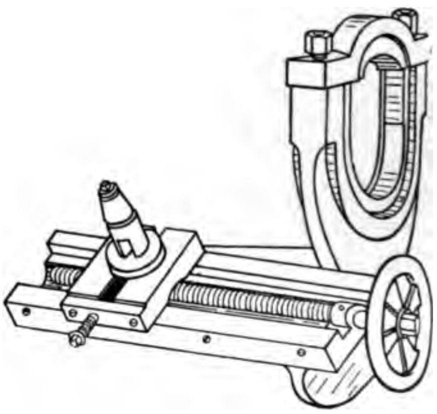
Fig. 60.

For turning off a commutator, a diamond-pointed tool should be used, this being better than either a round or square end. It should have a very sharp and smooth edge; and only a fine cut should be taken off each time in order to avoid catching in or tearing the copper, which is very tough. The surface is then finished by applying a "dead smooth" file while the commutator revolves rapidly in the lathe. Any particles of copper should then be carefully removed from between the bars.

To have the commutator wear smooth and work well, it is desirable to have the armature shaft move freely back and forth about an eighth of an inch in the bearings while it is running. A commutator should have a glaze of a brown or bronze color. A very bright or scraped appearance does not indicate the best condition. Sometimes a very little vaseline or a drop of oil may be applied to a commutator that is rough. Too much oil is very bad, and causes the following trouble:

CAUSE 4. **Brushes make poor contact with commutator.**

SYMPTOM. Close examination shows that brushes touch only at one corner, or only in front or behind, or there is dirt on surface of contact. Sometimes, owing to the presence of too much oil or from other cause, the brushes and commutator become very dirty, and covered with smut. They should then be carefully cleaned by wiping with oily rag or benzine, or by other means.

Occasionally a "glass-hard" carbon brush is met with. It is incapable of wearing to a good seat or contact, and will touch at only one or two points. Some carbon brushes are of abnormally high resistance, so that they do not make good contact. In such cases new brushes should be substituted.

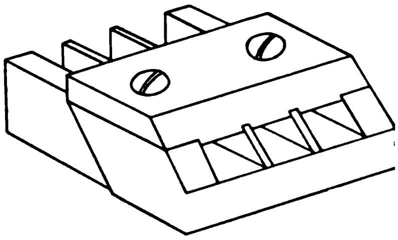

Fig. 61.

REMEDY. Carefully fit, adjust, or clean brushes until they rest evenly on commutator, with considerable surface of contact and with sure but not too heavy pressure. Copper brushes require a regular brush jig (Fig. 61). Carbon brushes can be fitted perfectly by drawing a strip of sandpaper back and forth between them and the commutator while they are pressing down. A band of sandpaper may be pasted or tied around the commutator, and the armature then slowly revolved by hand or by power while the brushes are pressed upon it.

It sometimes happens that the brushes make poor contact because the brush-holders do not work freely.

CAUSE 5. **Short-circuited or reversed coil or coils in armature.**

SYMPTOM. A motor will draw excessive current, even when running free without load. A dynamo will require considerable power, even without any load. For reversed coil, see III, 5.

The short-circuited coil is heated much more than the others, and is liable to be burnt out entirely; therefore the machine should be stopped immediately. If necessary to run machine in order to locate the trouble, one or two minutes is long enough; but this may be repeated until the short-circuited coil is found by feeling the armature all over.

An iron screw-driver or other tool held between the field magnets near the revolving armature, vibrates very perceptibly as the short-circuited coil passes. Almost any armature, particularly one with teeth, will cause a slight but rapid vibration of a piece of iron held near it; but a short circuit produces a much stronger effect only *once* per revolution. Care should be taken not to let the piece of iron be drawn in and jam the armature.

The current pulsates and torque is unequal at different parts of a revolution, these being particularly noticeable when several coils are short-circuited or reversed and the armature is slowly turned. If a large portion of the armature is short-circuited, the heating is distributed and is harder to locate. In this case a motor runs very slowly, giving little power but having full field magnetism. A short-circuited coil can also be detected by the drop-of-potential method. For dynamos, see IX, 3.

REMEDY. A short circuit is often caused by a piece of solder or other metal getting between the commutator-bars or their connections with the armature; and sometimes the insulation between or at the ends of these bars is bridged over by a particle of metal. In any such case the trouble is easily found and corrected. If, however, the short circuit is in the coil itself, the only effective remedy is to rewind the coil.

One or more "grounds" in the armature may produce effects similar to those arising from a short circuit. (See Cause 7.)

CAUSE 6. **Broken circuit in armature.**

SYMPTOM. Commutator flashes violently while running, and commutator-bar nearest the break is badly cut and burnt; but in this case no particular armature coil will be heated as in the last case; and the flashing will be very much worse, even when turning slowly. This trouble, which might be confounded with a bad case of "high bar" in commutator (Cause 3), is distinguished therefrom by slowly turning the armature, when violent flashing will continue if circuit is broken; but not with "high bar" unless it is very bad, in which case it is easily felt or seen. A very bad contact has almost the same effect as a break in the circuit.

Remedy. A break or bad contact can be located by the "drop" method (page 63) or by a continuity test (page 68). The trouble is often found where the armature wires connect with the commutator, and not in the coil itself, and the break may be repaired or the loose wire properly fastened. If the trouble is due to a broken commutator connection, and cannot be fixed, the disconnected bar may be temporarily connected to the next by solder, or the brushes may be "staggered," that is, one put a little forward and the other back so as to bridge over the break (Fig. 62). It may be impracticable to "stagger" radial and some other arrangements of brushes, but usually a brush is thick enough to make contact with more than one commutator bar. If the break is in the coil itself, rewinding is generally the only cure. But this may be remedied temporarily by connecting together by wire or solder the two commutator-bars or coil-terminals between which the break exists. It is only in an emergency that armature coils should be cut out or commutator bars connected together, or other makeshifts resorted to; but it sometimes avoids a very undesirable stoppage. A very rough but quick and simple way to connect two commutator bars, is to hammer or otherwise force the coppers together across the mica insulation at the end of the commutator. This should be avoided if possible; but if it has to be done in an emergency, the crushed material can afterwards be picked out and the injury smoothed over. In carrying out any of these methods, great care should be taken not to short-circuit any other armature coil, which would cause sparking (Cause 5).

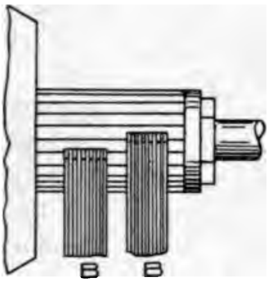

Fig. 62.

CAUSE 7. **Ground in Armature.**

SYMPTOM. Two "grounds" (accidental connections between the conductors on the armature and its iron core or the shaft or spider) would have practically the same effect as a short circuit (Cause 5), and would be treated in the same way. A single ground would have little or no effect, provided the circuit is not intentionally or accidentally grounded at some other point. On an electric-railway ("trolley") or other circuit employing the earth as a return conductor, one or more grounds in the armature would allow the current to pass directly through them, and would cause the motor to spark and have a variable torque at different parts of a revolution.

REMEDY. A ground can be detected by testing with a magneto bell (page 67). It can also be located by the drop-of-potential method (page 63). Another way to locate it is to wrap a wire around the commutator so as to make connection with all of the bars, and then connect a source of current to this wire and to the armature core (by pressing a wire upon the latter). The current will then flow from the armature conductors through the ground connection to the core, and the magnetic effect of the armature winding will be localized at the point where the ground is. This point is then found by the indications of a compass needle when slowly moved around the surface of the armature. The current may be obtained from a storage battery or from the circuit, but should be regulated by lamps or other resistance so as not to exceed the normal armature current. Sometimes the ground may be in a place where it can be corrected without much trouble, but usually the particular coil and often others must be rewound. A ground will be produced if the insulation is punctured by a spark of static electricity, which may be generated by the friction of the belt. If the frame of the machine is connected to the ground, the static charge will pass off to the ground; but such grounding is often inadvisable, and in such cases the frame may be connected to the ground through a Geissler tube, a wet thread, a heavy pencil-mark on a piece of unglazed porcelain, or other very high resistance which will carry off a static charge of very high potential and almost infinitesimal quantity, but will not permit the passage of any considerable current that might cause trouble.

CAUSE 8. **Weak Field Magnetism.**

SYMPTOM. Pole pieces not strongly magnetic when tested with a piece of iron. Point of least sparking is shifted considerably from normal position, owing to relatively strong distorting effect of armature magnetism. Speed of a shunt motor is usually high unless magnetism is very weak or *nil*, in which case a motor may run slow, stop, or even run backwards.* A generator fails to generate the full E.M.F. or current.

The particular cause of trouble may be found as follows: A broken circuit in the field of a motor is found by purposely opening the field circuit at some point, taking care first to disconnect armature (by putting wood under the brushes, for example), and to use only one hand, to avoid shock. If there is no spark when circuit is thus opened, there must be a broken circuit somewhere. A short circuit in the field coils is found by measuring their resistance roughly to see if it is very much less than it should be. Usually a short circuit is confined to one magnet, and will therefore weaken that one more than the others; and a piece of iron held half-way between the pole pieces will be attracted to one more than to the other. The short circuit may be found by the drop-of-potential method, by testing from the joint between the field coils to each outside terminal. "Grounding" is practically identical with short-circuiting, but one ground will not produce this effect until another occurs. A double ground, through which the current finds a complete path, is equivalent to a short circuit. In the ordinary "trolley" electric-railway system, a ground return is used, and the neutral conductor of three-wire systems is often grounded. In such cases one ground may be sufficient to cut out one or more field coils.

If one field coil is reversed and opposed to the others, it will weaken the field magnetism and cause bad sparking. This may be detected by examining the field coils to see if they are all connected in the right way, or by testing with a compass needle. (See IX, 4.) The series-coil of a compound-wound dynamo or motor is ofted connected wrongly, and will have the wrong effect, that is, will reduce the voltage of the former or raise the speed of the latter with increase of load.

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* NOTE. If the motor is not loaded, it will race.

REMEDY. A broken or short circuit or a ground is easily repaired if external or accessible. If it is internal, the only remedy is to replace or rewind the faulty coil. A shunt motor will spark badly in starting if the armature is connected before the field. This can be remedied by adjusting the contacts and switch-arm. If the voltage is too low on the circuit, it may cause sparking in a shunt dynamo or motor; and if the voltage cannot be raised, the resistance of the field circuit should be reduced by unwinding a few layers of wire or by substituting other coils (See VII, VIII, IX, and X.)

CAUSE 9. **Vibration of Machine.**

SYMPTOM. Considerable vibration is felt when the hand is placed upon the machine, and sparking decreases if the vibration is reduced.

REMEDY. The vibration is usually due to an imperfectly balanced armature or pulley (see VI, 1), to a bad belt (see VI, 6), cr to unsteady foundations; and the remedies described for these troubles should be applied.

Any considerable vibration is likely to produce sparking, of which it is a common cause. This sparking can be reduced by increasing the pressure of the brushes on the commutator, but the vibration itself should be overcome.

CAUSE 10. **Chatter of Brushes.**

The commutator sometimes becomes sticky when carbon brushes are used, causing friction, which throws the brushes into rapid vibration as the commutator revolves, similar to the action of a violin bow.

SYMPTOM. Slight tingling or jarring is felt in brushes.

REMEDY. Clean commutator, and oil slightly.

CAUSE 11. **Flying break in armature conductor.**

SYMPTOM. No break found by test with armature standing still, but break shown by flashing at brushes, when running, being usually due to centrifugal force.

REMEDY. Tighten connections to commutator, or repair broken wire, etc.

EXCESSIVE HEATING IN GENERATOR OR MOTOR.

General Instructions. The degree of heat that is injurious or objectionable in a generator or motor is easily determined by feeling the various parts. If the heat is bearable to the hand, it is entirely harmless; but if unbearable, the safe limit of temperature has been approached or passed, and the heat should be reduced in some of the ways that are indicated below. In testing with the hand, allowance should be made for the fact that bare metal feels much hotter than cotton at the same temperature. The back of the hand is more sensitive than the palm for this test. If the heat has become so great as to produce an odor or smoke, the safe limit has been far exceeded, and the current should be shut off immediately and the machine stopped, as this indicates a serious trouble, such as a short-circuited coil or tight bearing. The machine should not again be started until the cause of the trouble has been found and positively overcome. Of course, neither water nor ice should ever be used to cool electrical machinery, except possibly the bearings of large machines at points where they can be applied without danger of wetting the other parts.

Feeling for heat will serve as a rough test to detect excessive temperatures or in emergencies; but, of course, the sensitiveness of the hand varies, and it makes a great difference whether the surface is a good or bad conductor of heat. The proper and reliable methods for determining rise in temperature are given on page 59, Part I.

It is very important, in all cases of heating, to locate the source of heat in the exact part in which it is produced. It is a common mistake to suppose that any part of a machine that is found to be hot is the seat of the trouble. A hot bearing may cause the armature or commutator to heat, or *vice versa*. In every case all parts of the machine should be tried to find which is the hottest, since heat generated in one part is rapidly diffused throughout the entire machine. It is better to make observations for heating by starting with the whole machine cool, which is done by letting it stand for several hours.

II. HEATING OF COMMUTATOR AND BRUSHES.

CAUSE 1. **Heat spread from another part of machine.**

SYMPTOM. Start with the machine cool, and run for a short time, so that heat will not have time to spread. The real seat of trouble is the part that heats first.

REMEDY. (See Heating of Armature, Fields, and Bearings.)

CAUSE 2. **Sparking.** Any of the causes of sparking will cause heating, which may be slight or serious.

SYMPTOM and REMEDY. See "Sparking."

CAUSE 3. **Tendency to spark, or slight sparking hardly visible.**

Sometimes before sparking appears, serious heating is produced by the causes of sparking, such as the short-circuiting of the coils as their commutator-bars pass under the brushes.

SYMPTOM. Reduced by applying the principal remedies for sparking, such as slightly shifting rocker-arm. Fine sparks may be found by sighting in exact line with the surface of contact between the commutator and brushes.

REMEDY. (See "Sparking.") Apply the remedies with extra care. This incipient sparking may be due to excessive inductance in the armature coils, which can be corrected only by reconstruction; or it may be due to insufficient field strength, and this can be cured by increasing the ampere-turns of field winding.

CAUSE 4. **Overheated commutator will decompose carbon brush.**

The effect is to cover commutator with a black film which offers resistance and aggravates the heat.

SYMPTOM. Commutator covered with dark coating; commutator, brushes and holders show marks of abnormal heat.

REMEDY. Commutator and brushes should be carefully cleaned, and the latter adjusted to make good contact at the proper points.

CAUSE 5. **Bad connections in brush-holder, cable, etc.**

SYMPTOM. Holder, cable, etc., feel hottest; unusual resistance found in these parts by "drop method."

REMEDY. Improve the connections.

CAUSE 6. **Arcing or short circuit in commutator.**

This may occur across mica or insulation between bars or nuts.

SYMPTOM. Burnt spot between parts; spark appears in the insulation when current is put on.

REMEDY. Pick out the charred particles; take commutator apart and repair; or put on new commutator.

CAUSE 7. **Carbon brushes heated by the current.**

Carbon brushes require less attention than copper, because ıey do not cut the commutator, and their resistance usually reuces sparking, but it may also cause them to heat.

Symptom. Brushes hotter than other parts.

Remedy. Use carbon of higher conductivity. Let the rush-holder grip brush closer to commutator, so as to reduce the ɜngth of brush through which the current must pass. Reinforce he brush with copper gauze or sheet copper. Use larger brushes r a greater number.

III. HEATING OF ARMATURE.

Cause 1. **Excessive current in armature coils.**

Symptom and Remedy the same as in case of "Sparking," ˈause 1.

Cause 2. **Short-circuited armature coils.**

Symptom and Remedy the same as in case of "Sparking;" ˈause 5. See also Cause 7.

Cause 3. **Moisture in armature coils.**

Symptom. Armature requires considerable power to run free. ɹrmature steams when hot, or feels moist. This is really a pecial case of Cause 2, as moisture has the effect of short-circuitıg the coils through the insulation. Measure insulation resistnce of armature ; this should test at least one megohm if armaıre is in good condition, but would be much lowered by moisıre. (See "Insulation Tests.")

Remedy. The armature should be baked for 5 to 10 hours ı an oven or other place sufficiently warm to drive out the moisıre, but not hot enough to run any risk of burning or even lightly charring the insulation. A neat way to do this is to pass ırough the armature a current regulated to be about three quarɜrs of the rated armature current, the armature being held still r turned over occasionally.

Cause 4. **Foucault currents in armature core.**

Symptom. Iron of armature core hotter than coils after a hort run, and considerable power required to run armature when

Note. Any excess of current taken by an armature when running *free*, hatever the cause, must be converted into heat by some defect in the otor; hence the "free current" is the simplest and most complete test of the fficiency and perfect condition of the machine.

field is magnetized and there is no load on armature. This can be distinguished from Cause 2 by absence of sparking and absence of excessive heat in a particular coil or coils after a short run. (See "Stray Power Tests.")

Remedy. Armature core should be laminated more perfectly, which is a matter of first construction.

Cause 5. **One or more reversed coils on one side of armature.** This will cause a local current to circulate around armature.

Symptom. Excessive current when running free, but no particular coil heated more than others. If a moderate current is applied to each coil in succession by touching wires carrying current to each two adjacent commutator-bars, a compass needle held over the coils will behave differently when the reversed coil is reached. In a motor the half of armature containing the reversed coils is heated more than the other.

Remedy. Reconnect the coil to agree with the others.

Cause 6. **Heat conveyed from other parts.**

Symptom. Other parts hotter than armature. Start with machine cool, and see if other parts heat first.

Remedy. See Heating of Bearings, Field and Commutator.

Cause 7. **Flying cross in armature conductor.**

Symptom and Remedy similar to the case of sparking (Cause 11), except that reference here is to the insulation of the conductors.

IV. HEATING OF FIELD MAGNETS.

Cause 1. **Excessive current in field circuit.**

Symptom. Field coils too hot to keep the hand on. Their temperature more than 50 C above that of room by resistance test or by thermometer.

Remedy. In the case of a shunt-wound machine, decrease the voltage at terminals of field coils; or increase the resistance in field circuit by winding on more wire or putting resistance in series. In the case of a series-wound machine, shunt a portion of, or otherwise decrease, the current passing through field; or take a layer or more of wire off the field coils; or rewind with coarser wire. This trouble might be due to a short circuit in field coils in the case of a shunt-wound dynamo or motor, and would be indicated by the pole piece with the short-circuited coil being weaker than the others. This coil is cooler than the others; in fact, if completely short-circuited, it is not heated at all. This condition can be remedied only by rewinding the short-circuited coil. Measure resistance of the field coils to see if they are nearly equal. (See "drop method.") If the difference is considerable (say, more than 5 or 10 per cent), it is almost a sure sign that one coil is short-circuited or double-grounded.

CAUSE 2. **Foucault currents in pole pieces or field cores.**

SYMPTOM. The pole pieces hotter than the coils after a short run. When making the comparison, it is necessary to keep the hand on the coils some time before the full effect is reached, because the coils are insulated and the pole pieces are bare metal, and even then the coils will not feel so hot, although their actual temperature may be higher if measured by a thermometer.

REMEDY. This trouble is due to faulty design of toothed-armature machines, which can be corrected only by rebuilding, or is caused by fluctuations in the current. The latter can be detected, if the variations are not too rapid, by putting an ammeter in circuit; or rapid variations may be felt by holding a piece of iron near the pole pieces, and noting whether it vibrates. In the case of an alternating current it is necessary to use laminated fields to avoid great heating.

CAUSE 3. **Moisture in field coils.**

SYMPTOM. The field circuit tests lower in resistance than normal in that type of machine; and in the case of shunt-wound machines, the field takes more than the ordinary current. Field coils steam when hot, or feel moist to hand. The insulation resistance also tests low.

REMEDY. The same as for moisture in armature (III, 3).

V. HEATING OF BEARINGS.

The cause should be found and removed promptly, but heating of the bearings can be reduced temporarily by applying cold water or ice to them. This is allowable only when absolutely necessary to keep running; and great care should be taken not to allow any water to get upon the commutator, armature, or field-coils, as it might short-circuit or ground them. If the bearing is very hot, the shaft should be kept revolving slowly, as it might "freeze," or stick fast, if stopped entirely.

CAUSE 1. **Lack of oil.**

SYMPTOM. Oil-cup reservoir empty. Oil passages clogged. Self-oiling rings stick fast. Shaft and bearing look dry. The shaft does not turn freely.

REMEDY. Supply oil, and make sure that oil passages as well as feeding or self-oiling devices work freely, and that the oil cannot leak out. This last fault sometimes causes oil to fail sooner than attendant expects. A good quality of oil should always be used, as poor oil might be as bad as no oil.

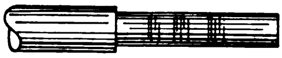

Fig. 63.

CAUSE 2. **Grit or other foreign matter in bearings.**

SYMPTOM. Best detected by removing shaft or bearing and examining both. Any grit can of course be felt easily, and will also cut the shaft.

REMEDY. Remove shaft or bearing, clean both very carefully, and see that no grit can get in. Place machine in dustless place or box it in. The oil should be perfectly clean; if not, it should be filtered. If it is not possible to stop the machine or to remove the shaft, the dirt may be washed out with kerosene or water; but these should not be allowed to get on the commutator, armature, or field coils.

CAUSE 3. **Shaft rough or cut.** (Fig. 63.)

SYMPTOM. Shaft will show grooves or roughness, and will probably revolve stiffly.

REMEDY. Turn shaft in lathe; or smooth with fine file; and see that bearing is smooth and fits shaft.

CAUSE 4. **Shaft and bearing fit too tight.**

SYMPTOM. Shaft hard to revolve by hand.

REMEDY. Turn or file down shaft in lathe, or scrape or ream out bearings.

CAUSE 5. **Shaft "sprung" or bent.**

SYMPTOM. Shaft hard to revolve, and usually sticks much more in one part of revolution than in another.

REMEDY. It is very difficult to straighten a bent shaft. It might be bent back or turned true, but probably a new shaft will be necessary.

Cause 6. **Bearings out of line.**

Symptom. Shaft hard to revolve, but is much relieved by slightly loosening the screws that hold bearings in place, when machine is not running and when belt, if any, is taken off.

Remedy. Loosen the bearings by partly unscrewing bolts or screws holding them in place, and find their easy and true position, which may require one of them to be moved either sideways or up or down; then file the screw-holes of that bearing, or raise or lower it, as may be necessary, to make it occupy the right position when the screws are tightened. The armature, however, must be kept in the center of the space between the pole pieces, so that the clearance is uniform all around. (See Cause 9.)

Cause 7. **Thrust or pressure of pulley, collar, or shoulder on shaft against one or both of the bearings.**

Symptom. Move shaft back and forth with a stick applied to the end while revolving, and note if the collar or shoulder tends to be pushed or drawn against either bearing. It is usually desirable that a shaft should move freely back and forth about an eighth of an inch, to make commutator and bearings wear smoothly.

Remedy. Line up the belt; shift collar or pulley; turn off shoulder on shaft, or file off bearing, until the shoulder does not touch when running, or until pressure is relieved.

Cause 8. **Too great a load or strain on the belt.**

Symptom. Great tension on belt. In this case the pulley bearing will probably be very much hotter than the other, and also worn elliptical, as indicated in Fig. 64, in which case the shaft can be shaken in the bearing in the direction of the belt pull, when the belt is off, provided the machine has been running long enough to wear the bearings.

Remedy. Reduce load or belt tension, or use larger pulleys and lighter belt, so as to relieve side strain on shaft. (See "Belting.")

Cause 9. **Armature too near one pole piece, producing much greater magnetic attraction on nearer side.**

Symptom. Examine the clearance of armature to see if it is uniform on all sides. Charge and discharge the field magnet, the armature being disconnected (by putting wood under the brushes);

and note whether armature seems to be drawn to one side and turns very much less easily when field is magnetized.

Remedy. This fault is due either to a defect in the original construction, or to wear in the bearings, either of which is difficult to correct; but in cases of necessity the armature can be centered exactly in the field by moving the bearings, which may be done by carefully filing the holes through which the screws pass that hold the bearings in place; or the pole piece may be filed away where it is too near the armature.

Trouble from this cause is greater in multipolar than in bipolar machines, and always tends to become aggravated, because the more the side pull the more the bearings wear in that direction. If, on the other hand, the armature is in the center of the space formed by the pole pieces, the magnetic pull is practically balanced in all directions.

It is risky to file bolt-holes or make any such change in a machine; and this should never be attempted before consulting an experienced machinist. Very often the trouble is due to the parts being out of place merely because they have not been put together right or because there is dirt between them. If the bearing is worn, it may be rebabbitted or renewed.

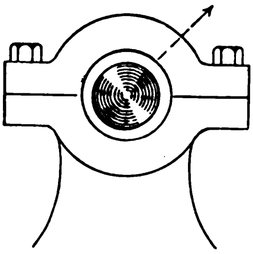

Fig. 64.

Cause 10. **Bearing heated by hot pulley, commutator, or armature.**

Symptom. Pulley, armature, or commutator hotter than bearing. The slipping of the belt on the pulley, sparking at the commutator, or heating of the armature may heat one or both bearings of the machine, in which case an examination will show that these parts are hotter than the bearing, and the real source of the trouble.

Remedy. A slipping belt, sparking commutator, or hot armature can be cured as described under these headings, and then the bearing will probably cease to heat.

VI. NOISY OPERATION.

Cause 1. **Vibration due to armature or pulley being out of balance.**

Symptom. Strong vibration felt when the hand is placed upon the machine while it is running. Vibration changes greatly if speed is changed, and sometimes almost disappears at certain speeds.

Remedy. Armature or pulley must be perfectly balanced by securely attaching lead or other weight on the light side, or by drilling or filing away some of the metal on the heavy side. The easiest method of finding in which direction the armature is out of balance is to take it out, and to rest the shaft on two parallel and horizontal A-shaped metallic tracks sufficiently far apart to allow the armature to go between them (Fig. 65). If the armature is then slowly rolled back and forth, the heavy side will tend to turn downward. The armature and pulley should always be balanced separately. An excess of weight on one side of the pulley and an equal excess of weight on the opposite side of the armature will not produce a balance while running, though it does when standing still; on the contrary, it will give the shaft a strong tendency to "wobble." A perfect balance is obtained only when the weights are directly opposite, *i.e.*, in the same line perpendicular to the shaft.

Cause 2. **Armature strikes or rubs against pole pieces.**

Symptom. Easily detected by placing the ear near the pole pieces; or by examining armature to see if its surface is abraded at any point; or by examining each part of the space between armature and field as armature is slowly revolved, to see if any portion of it touches or is so close as to be likely to touch when the machine is running. In small machines, the armature may be turned by hand, noting whether it sticks at any point.

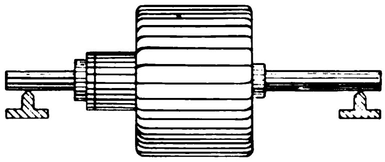
Fig. 65.

Remedy. Bind down any wire or other part of the armature that may project abnormally; or file out the pole pieces where the armature strikes; or center the armature so that there is a uniform clearance between it and the pole pieces at all points.

Cause 3. **Shaft collar or shoulder, hub or edge of pulley, or belt, strikes or scrapes against bearings.**

Symptom. Rattling noise, which stops when the shaft or pulley is pushed lengthwise away from one or the other of the bearings. (See "Heating of Bearings," Cause 7.)

Remedy. Shift the collar or pulley, turn off the shoulder on the shaft, file or turn off the bearing, move the pulley on the shaft, or straighten the belt, until there is no more striking, and the noise ceases.

Cause 4. **Rattling due to looseness of screws or other parts.**

Symptom. Close examination of the bearings, shaft, pulley, screws, nuts, binding-posts, etc., or touching the machine while running, or shaking its parts while standing still, shows that some parts are loose.

Remedy. Tighten up the loose parts, and be careful to keep them all properly set up. It is easy to guard against the occurrence of this trouble, which is very common, by simply examining the various screws and other parts each day before the machine is started. Electrical machinery being usually high-speed, the parts are particularly liable to shake loose. A worn or poorly fitted bearing might allow the shaft to rattle and make a noise, in which case the bearing should be refitted or renewed.

Cause 5. **Singing or hissing of brushes.** This is usually occasioned by rough or sticky commutator (see "Sparking," Causes 3 and 10), or by brushes not being smooth, or by the layers of a copper brush not being held together and in place. With carbon brushes, hissing will be caused by the use of carbon that is gritty or too hard. Vertical carbon brushes, or brushes inclined against the direction of rotation, are liable to squeak or sing. Occasionally, a new machine will make noise that is reduced after the machine has been run for some time.

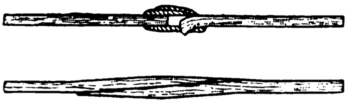

Fig. 66.

Symptom. Sound of high pitch, and easily located by placing the ear near the commutator while it is running, and by lifting off the brushes one at a time, provided there are two or more in each set, so that the circuit is not opened. If there is no current, there is no objection to raising the brushes.

Remedy. Apply a *very little* oil or vaseline to the commu-

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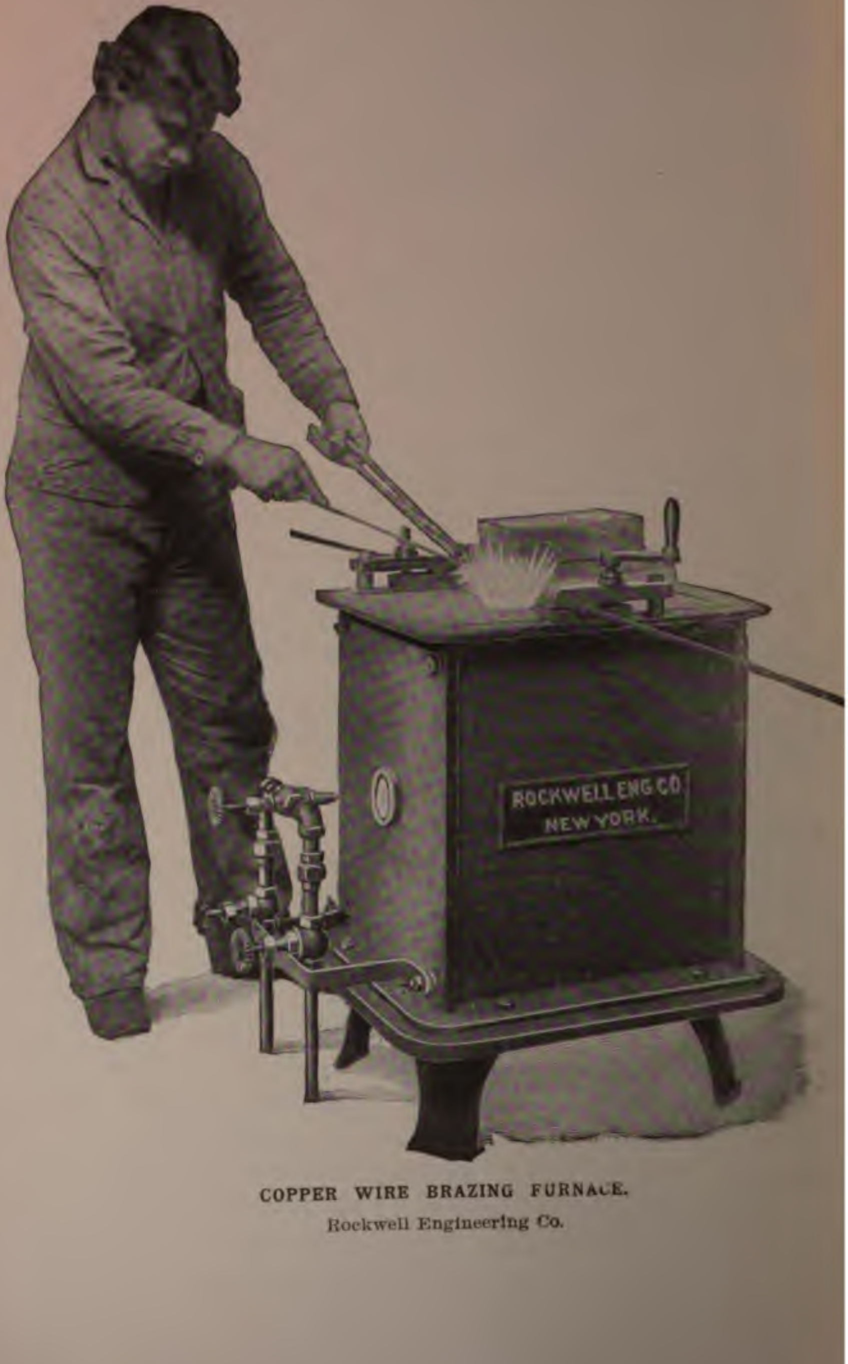


COPPER WIRE BRAZING FURNACE.
Rockwell Engineering Co.

tator with the finger or a rag. Adjust the brushes or smooth the commutator by turning or filing, or by using fine sandpaper, being careful to clean thoroughly afterwards. Carbon brushes are liable to squeak in starting up or at low speed. This decreases at full speed, and can generally be stopped by moistening the brushes with oil, care being taken not to have any drops or excess of oil. Shortening or lengthening the brushes sometimes stops the noise. Running the machine without load for some time usually reduces this trouble.

CAUSE 6. **Flapping or pounding of belt joint or lacing against pulley.** (Fig. 66.)

SYMPTOM. Sound repeated once for each complete revolution of the belt, which is much less frequent than any other generator or motor sound, and can easily be detected or counted.

REMEDY. Endless belt or smoother joint. (See "Belting.")

CAUSE 7. **Slipping of belt on pulley due to overload.**

SYMPTOM. Intermittent squeaking noise.

REMEDY. Tighten the belt or reduce the load. A wider belt or larger pulley may be required. Powdered rosin may be put on the belt to increase its adhesion: but it is a makeshift, injurious to the belt, to be adopted only if necessary. (See "Belting.")

CAUSE 8. **Humming of armature-core teeth as they pass pole-pieces.**

SYMPTOM. Pure humming sound less metallic than Cause 5.

REMEDY. Slope or chamfer the ends of the pole pieces so that each armature tooth does not pass the edge of the pole piece all at once. Decrease the magnetization of the fields. Increase the air-gap or reduce the distance between the teeth. But these are nearly all matters of first construction and are made right by good manufacturers.

CAUSE 9. **Humming due to alternating or pulsating current.**

SYMPTOM This gives a sound similar to that in the preceding case. The two can be distinguished, if necessary, by determining whether the note given out corresponds to the number of alternations, or to the number of armature teeth passing per second.

Usually the latter is considerably greater than the former.

REMEDY. This trouble is confined to alternating apparatus, and its effects can be reduced by proper design and by mounting the machine so as to deaden the sound as far as possible.

It often happens that a generator or motor seems to make a noise, which in reality is caused by the engine or other machine with which it is connected. Careful listening with the ear close to the different parts will show exactly where the noise originates. A very sensitive method of locating a noise or vibration is to hold a short stick by one end between the teeth, and press the other end squarely against the several parts, to ascertain which particular one gives the greatest vibration.

VII. SPEED TOO HIGH OR TOO LOW.

This is generally a serious matter in either generator or motor, and it is always desirable and often imperative to shut down immediately, and make a careful investigation.

SPEED TOO LOW.

CAUSE 1. **Overload.** (See "Sparking," Cause 1.)

SYMPTOM. Armature runs more slowly than usual. Bad sparking at commutator. Ammeter indicates excessive current. Armature heats. Belt very tight on tension side.

REMEDY. Reduce the load on machine, decrease the diameter of driving pulley, or increase the diameter of driven pulley. If necessary to relieve strain of overload, temporarily decrease the voltage on either a generator or a motor.

CAUSE 2. **Short circuit or ground in armature.**

SYMPTOM and REMEDY the same as in case of "Heating of Armature, Cause 2 and Cause 6.

CAUSE 3. **Armature strikes pole pieces.**

SYMPTOM and REMEDY the same as in case of "Noise," Cause 2.

CAUSE 4. **Shaft does not revolve freely in the bearings.**

SYMPTOM and REMEDY the same as for "Heating of Bearings," all cases.

SPEED TOO HIGH OR TOO LOW.

CAUSE 5. **Field magnetism weak.**

This has the effect, on a constant-voltage circuit, of making a motor run too fast if lightly loaded, or too slow if heavily loaded, or even run backwards if the field magnet is not excited at all, as, for example, when the field circuit is broken. It makes a generator fail to "build up" or excite its field, or give the proper voltage in any case.

Symptom and Remedy the same as in case of "Sparking," Cause 8. (See the following Cause; also "Dynamo Fails to Generate ')

Cause 6. **Too high or too low voltage on the circuit.**

Symptom. This would cause a motor to run too fast or too slow, respectively. It can be shown by measuring the voltage of the circuit.

Remedy. The central station or generating plant should be notified that voltage is not right.

SPEED TOO HIGH.

Cause 7. **Motor too lightly loaded.**

Symptom. A series-wound motor on a constant-potential circuit runs too fast, and may speed up to the bursting point if the load is very much reduced or removed entirely (by the breaking of the belt, for example).

Remedy. Care should be exercised in using a series motor on a constant-potential circuit, except where the load is a fan, pump, or other machine that is *positively* connected or geared to the motor so that there is no danger of its being taken off. A shunt motor should be used if the load is likely to be thrown off.

VIII. MOTOR STOPS OR FAILS TO START.

This is an extreme case of the previous class ("Speed Too High or Too Low"), but is separated because it is more definite and permits of quicker diagnosis and treatment. This heading does not, of course, apply to generators, since any trouble in setting these in motion is usually outside of the machine itself.

Cause 1. **Great overload.**

A slight overload causes motor to run slowly, but an extreme overload will, of course, stop it entirely or "stall" it. (See "Sparking," Cause 1.)

Symptom. On a constant-potential circuit the current is excessive, and safety-fuse blows or circuit-breaker opens. In their absence or failure, armature is burnt out.

Remedy. Turn off switch instantly, reduce or take off the load, replace the fuse or circuit-breaker, if necessary, and turn on current again just long enough to see if trouble still exists; if so, take off more load.

CAUSE 2. **Very excessive friction due to shaft, bearings, or other parts being jammed, or armature touching pole pieces.**

SYMPTOM. Similar to previous case, but distinguished from it by the fact that the armature is hard to turn even when load is taken off. Examination shows that the shaft is too large or is bent or rough, that the bearing is too tight, that the armature touches pole pieces, or that there is some other impediment to free rotation. (See "Heating of Bearings" and "Noise.")

REMEDY. Turn current off instantly, ascertain and remove the cause of friction, turn on the current again just long enough to see if trouble still exists ; if so, investigate further.

CAUSE 3. **Circuit open.**

This may be due to (*a*) safety-fuse blown or circuit-breaker open ; (*b*) wire in motor broken or slipped out of connections; (*c*) brushes not in contact with commutator ; (*d*) switch open ; (*e*) circuit supplying motor open ; (*f*) failure at generating plant.

SYMPTOM. Distinguished from causes 1 and 2 by the fact that if the load is taken off, the motor still refuses to start, and yet armature turns freely.

On a constant-potential circuit the field circuit alone of a shunt motor may be open, in which case the pole pieces are not strongly magnetic when tested with a piece of iron, and there is a dangerously heavy current in the armature ; if the armature circuit is at fault, there is no spark when the brushes are lifted ; and if both are without current, there is no spark when switch is opened. One should be very careful if there is no field magnetism or even if it is weak, as a motor is liable to be burnt out if the current is then thrown upon the armature.

REMEDY. Turn current off instantly. Examine safety-fuse circuit-breaker, wires, brushes, switch, and circuit generally, for break or fault. If none can be found, turn on switch again for a moment, as the trouble may have been due to a temporary stoppage of the current at the station or on the line. If motor still seems dead, test separately armature, field coils, and other parts of circuit for continuity with a magneto or a cell of battery and an electric bell, to see if there is any break in the circuit. (See "Instructions for Testing.")

One of the simplest ways to find whether the circuit has current on it and to locate any break, is to test through an incandescent lamp. Two or five lamps in series should be used on 220- and 500-volt circuits, respectively.

CAUSE 4. **Wrong connection or complete short circuit of field, armature, switch, etc.**

SYMPTOM. Distinguished from Causes 1 and 2 in the same way as Cause 3, and differs from Cause 3 in the evidence of strong current in motor.

On a constant-potential circuit, if current is very great, it indicates a short circuit. If the field is at fault, it will not be strongly magnetic.

The possible complications of wrong connections are so great that no exact rules can be given. Carefully examine and make sure of the correctness of all connections (see Diagrams of Connections). This trouble is usually inexcusable, since only a competent person should ever set up a machine or change its connections.

In the 3-wire (220-volt direct-current) system, several peculiar conditions may exist, as follows:

(*a*) The dynamo or dynamos on one side of the system may become reversed, so that both of the outside wires are positive or negative. In that case a motor fed in the usual way from the two outside conductors will get no current, but lamps connected between the neutral wire and either of the outside wires will burn as usual.

(*b*) If one of the outside wires is open by the blowing of a fuse, an accidental break, or other cause, then a motor (220-volt) beyond the break can get some current at 110 volts through any lamps that may be on the same side of the break as itself, and on the same side of the system as the conductor that is open. These lamps will light up when the motor is connected, but the motor will have little or no power unless the number of lamps is large.

(*c*) If the neutral or middle wire is open, a motor connected with the outside wires will run as usual; but lamps on one side of the system will burn more brightly than those on the other side, unless the two sides are perfectly balanced.

(*d*) If one of the outside wires becomes accidentally grounded, a 110-volt dynamo, motor, or other apparatus, also grounded and connected to the other outside wire, will receive 220 volts, which will probably burn it out.

IX. DYNAMO FAILS TO GENERATE.

This trouble is almost always caused by the inability of a dynamo to "excite" or "build up" its field-magnetism sufficiently. The proper starting of a self-exciting dynamo requires a certain amount of residual magnetism, which must be increased to full strength by the current generated in the machine itself. This trouble is not likely to occur in a separately-excited machine; and if it does it is usually due to the exciter failing to generate, and therefore amounts to the same thing.

CAUSE 1. **Residual magnetism too weak or destroyed.**

This may be due to (*a*) vibration or jar; (*b*) proximity of another dynamo; (*c*) earth's magnetism; (*d*) accidental reversed current through fields, not enough to completely reverse magnetism. The complete reversal of the residual magnetism in any dynamo will not prevent its generating, but will only make it build up of opposite polarity. Sometimes reversal of residual magnetism may be very objectionable, as in case of charging storage batteries; but, although the popular supposition is to the contrary, it will not cause the machine to fail to generate.

SYMPTOM. Little or no magnetic attraction when the pole pieces are tested with a piece of iron.

REMEDY. Send a magnetizing current from another machine or battery through the field coils, then start and try the machine; if this fails, apply the current in the opposite direction, since the magnets may have enough polarity to prevent the battery building them up in the direction first tried.

Shift the brushes backward in a generator, or forward in a motor to make armature magnetism assist field. Turn machine around or change its polarity, so that the magnetism which the earth or the adjacent machine tends to induce is in the right direction. Dynamos should be placed with their opposite poles toward each other, and the north pole of a machine should preferably be placed toward the north (which is magnetically the *south* pole of the earth); but the earth's magnetism is hardly strong enough to reverse a dynamo's residual magnetism.

CAUSE 2. **Reversed connections or reverse direction of rotation.**

SYMPTOM. When running, pole pieces show no attraction for a piece of iron. The application of external current cannot be made to start the machine, as in case of Cause 1, because, whichever way the field may be magnetized, the resulting current generated by armature opposes and destroys the magnetism.

REMEDY. (*a*) Reverse either armature connections or field connections, *but not both.* (*b*) Move brushes through 180° for 2-pole, 90° for 4-pole machines, etc. (*c*) Reverse direction of rotation. After each of the above are tried, the field may have to be built up with a battery or other current, since the causes in this case operate to destroy whatever residual magnetism may have been present.

CAUSE 3. **Short circuit in the machine or external circuit.**

This applies to a shunt-wound machine, and has the effect of preventing the voltage and the field magnetism from building up.

SYMPTOM. Magnetism weak, but still quite perceptible.

REMEDY. If the short circuit is in the external circuit, opening the latter will allow the dynamo to build up and generate full voltage. If the short circuit is within the machine, it should be found by careful inspection or testing. In either of these cases, do not connect the external circuit until short circuit is found and eliminated. A slight short curcuit, such as that caused by a defective lamp socket or by copper dust on the brush-holder or commutator, may prevent the magnetism of a shunt machine from building up. (See "Sparking," Causes 5 and 8.) Too many lamps, or other load, might prevent a shunt dynamo from building up its field magnetism, in which case the load should be disconnected in starting.

CAUSE 4. **Field-coils opposed to each other.**

SYMPTOM. Upon passing a current from another dynamo of a battery the following symptom will exist: If the pole-pieces of a bipolar machine are approached with a compass or other freely suspended magnet, they both attract the same end of the magnet, showing them to be of the same polarity, whereas they should always be of opposite polarity.

For similar reasons the pole-pieces are magnetic when tested separately with a piece of iron, but show less attraction when the same piece of iron is applied to both at once, in which latter case the attraction should be stronger. In multipolar machines these tests should be applied to consecutive pole-pieces.

REMEDY. Reverse the connections of one of the coils in order to make the polarity of the pole-pieces opposite. The pole-pieces should be alternately north and south (when tested by compass).

CAUSE 5. **Open circuit.**

This may be due to (*a*) broken wire or faulty connection in machine; (*b*) brushes not in contact with commutator; (*c*) safety fuse melted or absent; (*d*) switch open; (*e*) external circuit open.

SYMPTOM. If the trouble is merely due to the switch or external circuit being open, the magnetism of a shunt dynamo may be at full strength, and the machine itself may be working perfectly; but if the trouble is in the machine, the field magnetism will probably be very weak.

REMEDY. Make very careful examination for open circuit; if not found, test separately the field-coils, armature, etc., for continuity, with magneto or cell of battery and electric bell. (See "Instructions for Testing;" also "Motor Stops," etc., Cause 3.)

A break, poor contact, or excessive resistance in the field circuit or regulator of a shunt dynamo will also make the magnetism weak and prevent its building up. This may be detected and overcome by cutting out the rheostat for a moment by connecting the two terminals of the field-coils to the two brushes respectively, care being taken not to make a short circuit.

A break or abnormally high resistance anywhere in the circuit of a series-wound dynamo will prevent it from generating, since the field-coil is in the main circuit. This may be detected and overcome by short-circuiting the machine for a moment in order to start up the magnetism.

Either of these two remedies by short-circuiting should be applied very carefully, and not until the pole-pieces have been tested with a piece of iron to make sure that the magnetism is weak.

CAUSE 6. **Brushes not in proper position.**

SYMPTOM. The magnetism and current are increased by shifting the brushes.

REMEDY. It often happens that the brushes are not set at the proper point; in fact, they may be set exactly wrong, so that the dynamo is incapable of generating any current whatever. This trouble is mainly due to the fact that the proper position for the brushes is not the same for all kinds of machines. Almost all ring armatures and many drum armatures require the brushes to be set opposite the *spaces* between the pole-pieces. But most armatures are wound so that the brushes must be set nearly 90° from this position, or opposite the center of the poles. Some multipolar machines have as many sets of brushes as there are pole pieces; while others have armatures that are cross-connected, or have the conductors arranged in series so that only two sets of brushes are required. Four-pole machines with only two brushes require them to be set at 90°; 6-pole machines, either 60° or 180°; 8-pole, either 45° or 135°; 10-pole, either 36°, 108°, or 180°; 12-pole, either 30°, 90°, or 130°; and 16-pole, either 22½°, 67½°, 112°, or 157½°; and so on.

The fact is, that the proper position of the brushes depends upon the particular winding, internal connections, etc., and *no one should ever assume to know where to set the brushes* unless he is perfectly familiar with the particular type of machine. A blue print or other definite instructions should always be obtained and followed; and, if these are not available, the matter may be determined by careful trial. The proper position of brushes is the same for dynamos and motors, except that in the former the brushes are given a forward lead, that is, shifted a little in the direction of rotation, whereas motor brushes should be set a little backward. This shifting is necessitated by the armature reaction or the magnetizing effect of the armature current, which distorts the field magnetism.

The positions and number of brushes for each kind of armature are show in Fig. 67, which shows also the *arrangements of circuits* in each of the leading types.

A is the armature for the ordinary two-pole machine, and may be drum- or ring-wound. The current enters from the positive

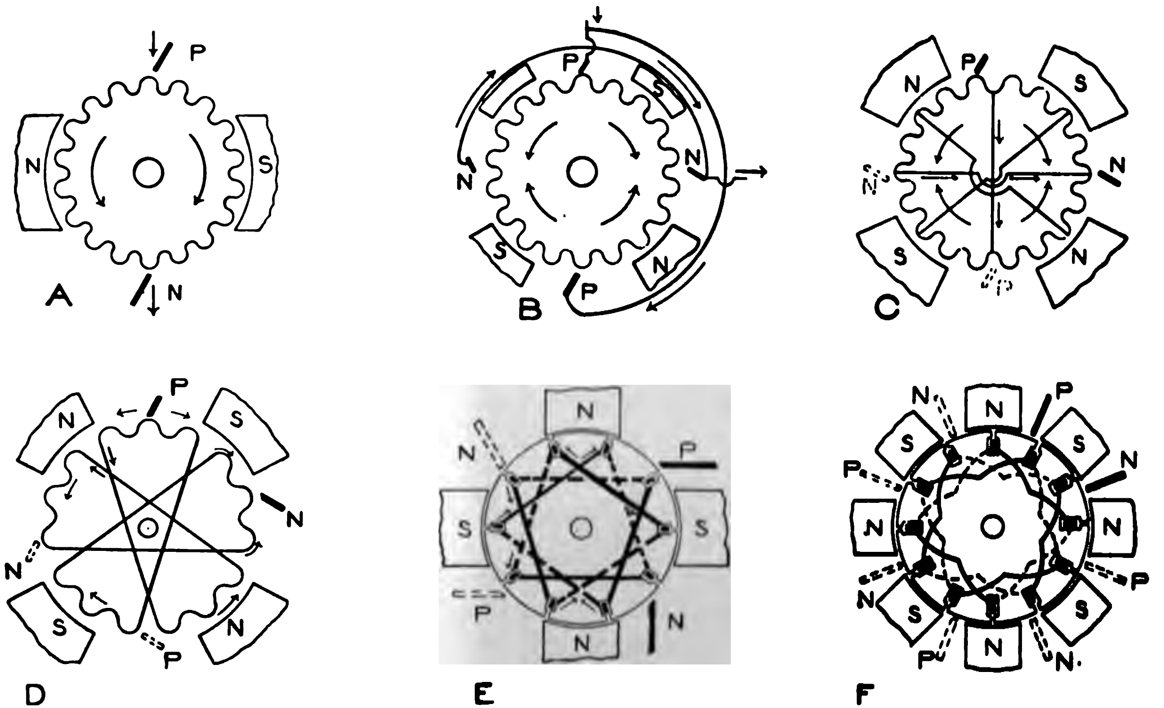


Fig. 67.

A = Two Pole, Two Circuit.
B = Four Pole, Four Circuit, Four Brushes in Multiple.
C = Four Pole, Four Circuit, Cross Connected, Two or Four Brushes in Multiple.
D = Four Pole, Two Circuit Ring, Two or Four Brushes in Multiple.
E = Four Pole, Two Circuit Drum, Two or Four Brushes in Multiple.
F = Eight Pole, Two Circuit Drum, Two, Four, Six, or Eight Brushes in Multiple.

brush, passes around both sides of the armature, and out through the negative brush. Hence this is called a "two-circuit" armature.

B is a plain armature used in a 4-pole machine. As there are here two more poles, it is necessary to use two more brushes to collect the current. This gives two brushes through which current enters, and two through which it leaves; consequently each pair of brushes must be joined in multiple in order to carry all the current to the mains.

C is a 4-pole armature in which the additional currents are carried across to the first pair of brushes by means of connections through the center of the armature. Therefore, the entire current may be taken off by these brushes; or two more may be added to divide the work, in which case they must also be connected in multiple to the first pair, as in case B above.

With either B or C, since there are two parts of the armature winding under the influence of different magnets, but running in parallel to the mains, it is evident that if the pressure of the current in one part of the winding is weaker than in the other, through inequality of the magnets or otherwise, it will short-circuit the other part of the winding and work badly.

This cannot occur in A, because both parts of the winding are influenced by the two ends of a single magnet.

D is a 4-pole armature in which the windings do not connect together in parallel but *in series*, thus overcoming the objection above. It has a ring-winding, and each coil is connected to the one diametrically opposite. An examination will show that though the poles alternate, the wire is all arranged so that the current flows in a single pair of circuits, as in A. This also permits of the use of larger wire and fewer turns, as they are connected in series instead of multiple.

E is a drum armature all in series, as in the case of D. Inspection will show that the actions of each of the four poles on all the bars harmonize, or cause the current to flow in the same direction.

To facilitate tracing the course of the current, the arrangement is represented with the smallest possible number of bars Many more are used in practice.

F is a series drum armature for eight poles. The principle is the same, but the limit of brush adjustment is smaller. The entire range from zero to full E. M. F. is covered by moving the brush one-eighth of the circumference.

As the winding is all in series, two brushes only are necessary; but as many more as desired may be added between the other poles, and then connected in multiple to the first ones. This is usually taken advantage of, because a single pair of brushes would become heated from carrying excessive current; but the difficulty of one part of the armature short-circuiting the other cannot occur, because *each part* of the winding is under the influence of all the poles.

X. VOLTAGE OF GENERATOR NOT RIGHT

VOLTAGE TOO LOW.

CAUSE 1. **Speed too low.** (See "Speed not Right.")

REMEDY. Increase speed of the prime mover, if possible; when this cannot be done, decrease the diameter of the driven pulley or increase the diameter of the driving pulley, preferably the latter.

CAUSE 2. **Field magnetism weak.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 8.)

CAUSE 3. **Brushes not in proper position.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 2.)

CAUSE 4. **Machine overloaded.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 1 and "Speed not Right," Cause 1); also increase field excitation, if possible.

CAUSE 5. **Short-circuited armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

CAUSE 6. **Reversed armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

VOLTAGE TOO HIGH.

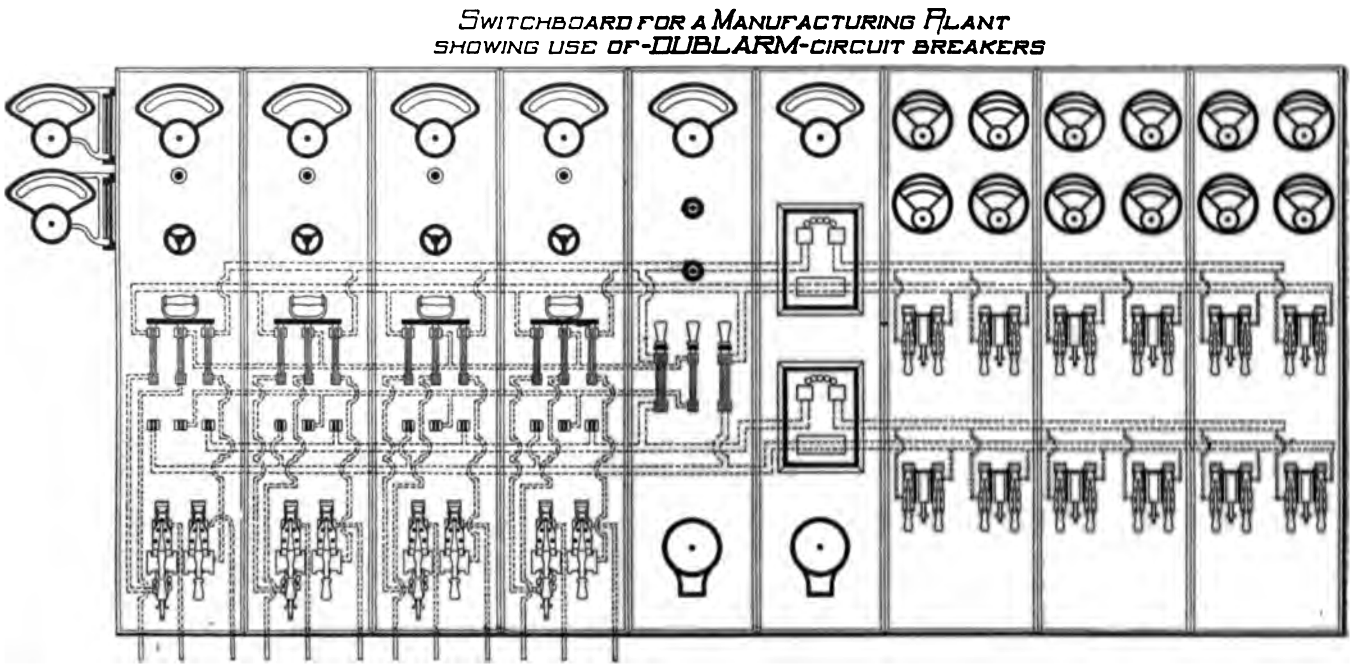
CAUSE 7. **Speed too high.**

REMEDY. Apply the reverse of treatment given in Cause 1.

CAUSE 8 **Field magnetism too powerful.**

REMEDY. Increase resistance of shunt field circuit, by means of a shunt field rheostat.

CAUSE 9. **Machine Compounds too much.**
REMEDY. Decrease resistance of series field shunt.
(See Compound-wound Dynamos, page 25, Part I.)


SWITCHBOARD FOR A MANUFACTURING PLANT
SHOWING USE OF -DUBLARM- CIRCUIT BREAKERS

SWITCHBOARD.

The Cutter Company.

ELECTRIC WIRING.

INSTALLING THE DYNAMO.

Dynamos should be located in a dry place so situated that the surrounding atmosphere is cool. If the surrounding air is warm, it reduces the safe carrying capacity of the machine and is likely to allow such temperature to rise in the machine itself as to burn out either armature or field, or both. A dynamo should not be installed where any hazardous process is carried on, nor where it would be exposed to inflammable gases or flying combustible materials, as the liability to occasional sparks from the commutator or brushes might cause serious explosions.

Wherever it is possible, dynamos should be raised or insulated above the surrounding floor, on wooden base frames, which should be kept filled to prevent the absorption of moisture, and also kept clean and dry. When it is impracticable to insulate a dynamo on account of its great weight, or for any other reason, the Inspection Department of the Board of Fire Underwriters having jurisdiction may, in writing, permit the omission of the wooden base frame, in which case the frame should be permanently and effectively grounded. When a frame is grounded, the insulation of the entire system depends upon the insulation of the dynamo conductors from the frame, and if this breaks down the system is grounded and should be remedied at once.

Grounding Dynamo Frames can be effectually done by firmly attaching a wire to the frame and to any main water pipe inside the building. The wire should be securely fastened to the pipe by screwing a brass plug into the pipe and soldering the wire to this plug. When the dynamo is direct driven, an excellent ground is obtained through the engine coupling and the piping of the engine and boiler.

Wherever high-potential machines have their frames grounded, a small board walk should be built around them and raised above the floor, or porcelain on glass insulators, in order that the dynamo tender may be protected from a shock when adjusting brushes or working about the machine.

Sufficient space should be left on all sides of the dynamo and especially at the commutator end, so that there may be ample room for removing armatures, commutators, or any other parts at any time.

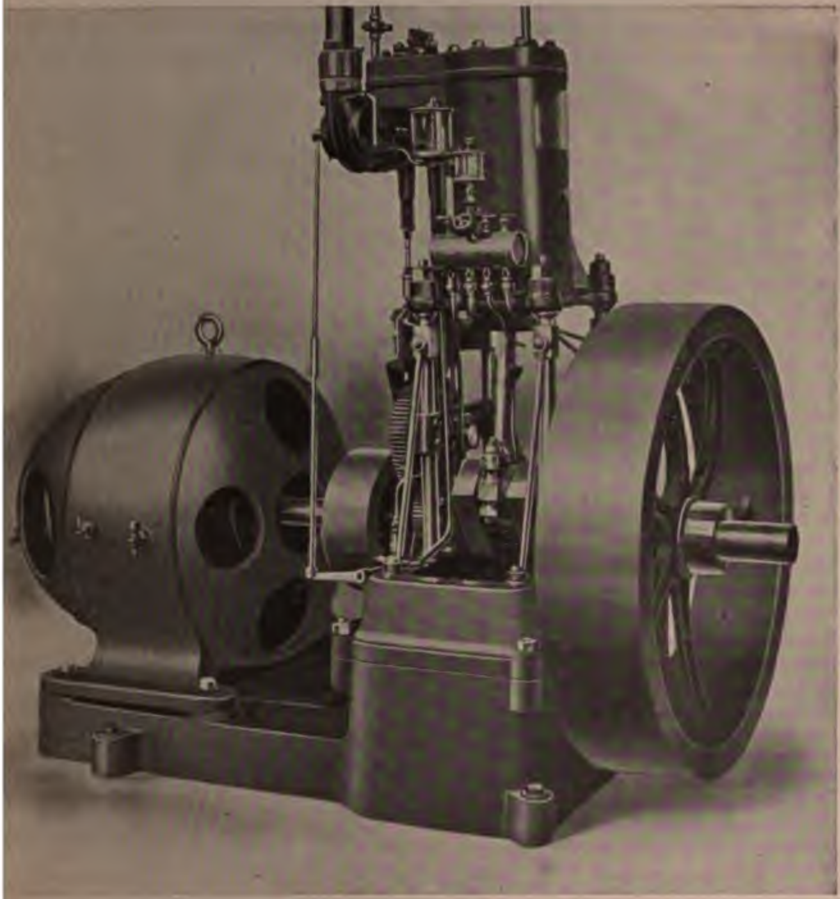
Circuit Breakers and Fuses. Every constant-potential generator should be protected from excessive current by a safety fuse or equivalent device of approved design, in each wire lead, such as a circuit breaker. The latter is preferable, on account of its being immeasurably more accurate and convenient for resetting. Such devices should be placed on or as near as possible to the dynamo. When the needs of the service make these devices impracticable, the Inspection Department having jurisdiction may, in writing, modify the requirements.

The best practice is to place the fuses on the dynamo itself, and the circuit breakers on the switchboard.

Waterproof Covers should be provided for every dynamo and placed over each machine as soon as it is shut down. Negligence in this matter has caused many an armature and field coil to burn out, as only a few drops of water are necessary to cause a short circuit as soon as the machine is started up again, which might do many dollars' worth of damage, to say nothing of the inconvenience caused by shutting off light or power when it is most needed, and for an indefinite length of time.

Name-Plates. Every dynamo should be provided with a name-plate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute. This will show exactly what the machine was designed for, and how it should be run.

Wiring from Dynamos to switchboards should be in plain sight or readily accessible, and should be supported entirely upon non-combustible insulators, such as glass or porcelain; in no case should any wire come in contact with anything except these insulators, and the terminals upon the dynamos and switchboards. When it becomes necessary to run these wires through a wall or floor, the holes must be protected by some approved non-combus-



5 KILOWATT, 80 LIGHT.

Secor Oil-Electric Generating Plant.

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ASTOR, LENOX
TILDEN FOUNDATIONS

insulating tube, such as glass or porcelain, and in every case
ube must be fastened so that it shall not slip or pull out.
ons of any tubing, whether armored or otherwise, that are
ped off for this purpose, should not be used. All wires for
mos and switchboard work should be kept so far apart that
is no liability of their coming in contact with one another,
should be covered with non-inflammable insulating material
ient to prevent accidental contact, except that bus bars may
ade of bare metal so that additional circuits can be readily
hed. Wires must have ample carrying capacity, so as not to
with the maximum current likely to flow through them under
al conditions. (See "Capacity of Wires Table," page 37.)

uch trouble in past years has arisen from faulty construction
itchboards, and the apparatus placed upon them, that strict
rements have been necessarily adopted by engineers as well
surance inspectors, and the following suggestions are recom-
led by the latter:

The Switchboard should be so placed as to reduce to a min-
ı the danger of communicating fire to adjacent combustible
rial, and, like the dynamo, should be erected in a dry place
kept free from moisture. It is necessary that it should be
sible from all sides when the wiring is done on the back of
oard, but it may be placed against a brick or stone wall when
iring is on the face.

The board should be constructed wholly of non-combustible
rial, but when this is impossible a hard-wood board made in
ton form, and well filled to prevent absorption of moisture, is
idered safe. Every instrument, switch or apparatus of any
placed upon the switchboard should have its own non-com-
ible insulating base. This is required of every piece of ap-
tus connected in any way with any circuit. If it is found
ssible to place the resistance box or regulator (which should,
ery case, be made entirely of non-combustible material) upon
switchboard, it must be placed at least one foot from com-
ible material or separated therefrom by a non-inflammable,
absorptive insulating material. A slate slab is preferable.
ial attention is called to the fact that switchboards should not

be built down to the floor, nor up to the ceiling, but a space of at least ten or twelve inches should be left between the floor and the board, and from eighteen to twenty-four inches between the ceiling and the board in order to prevent fire from communicating from the switchboard to the floor or ceiling, and also to prevent space being used for storage of rubbish and oily waste.

Lightning Arresters should be attached to each side of every overhead circuit connected with the station.

It is recommended to all electric light and power companies that arresters be connected at intervals over systems in such numbers and so located as to prevent ordinary discharges entering (over the wires) buildings connected to the lines. They should be located in readily accessible places away from combustible materials, and as near as practicable to the point where the wires enter the building.

Station arresters should generally be placed in plain sight on the switchboard. In all cases, kinks, coils and sharp bends in the wires between the arresters and the outdoor lines should be avoided as far as possible. Arresters should be connected with a thoroughly good and permanent ground connection by metallic strips or wires having a conductivity not less than that of a No. 6 B. & S. copper wire, and running as nearly as possible in a straight line from the arresters to the earth connection.

Ground wires for lightning arresters should not be attached to gas pipes within the buildings.

It is often desirable to introduce a choke coil in circuit between the arresters and the dynamo. In no case should the ground wire from a lightning arrester be put into iron pipes, as these would tend to impede the discharge.

Unless a good, damp ground is used in connection with all lightning arresters, they are practically useless. Ground connections should be of the most approved construction, and should be made where permanently damp earth can be conveniently reached. For a bank of arresters such as is commonly found in a power house, the following instructions will be found valuable: First, dig a hole six feet square directly under the arresters, until permanently damp earth has been reached; second, cover the bottom of this hole with two feet of crushed coke or charcoal (about pea size); third, over this lay twenty-five square feet of No. 16 copper plate; fourth, solder at least two ground wires, which should not be smaller than No. 6, securely across the entire surface of the ground plate; fifth, now cover the ground plate with two feet of crushed coke or charcoal; sixth, fill in the hole with earth, using running water to settle.

All lightning arresters should be mounted on non-combustible bases and be so constructed as not to maintain an arc after the discharge has passed; they should have no moving parts.

Testing of Insulation Resistance. All circuits except those permanently grounded should be provided with reliable ground detectors. Detectors which indicate continuously and give an instant and permanent indication of a ground are preferable. Ground wires from detectors should not be attached to gas pipes within the building.

Where continuously indicating detectors are not feasible, the circuits should be tested at least once per day.

Data obtained from all tests should be preserved for examination.

Storage or Secondary Batteries should be installed with as much care as dynamos, and in wiring to and from them the same precautions and rules should be adopted for safety and the prevention of leaks. The room in which they are placed should be kept not only dry, but exceptionally well aired, to carry off all fumes which are bound to arise. The insulators for the support of the secondary batteries should be glass or porcelain, as filled wood alone would not be approved.

Care of Dynamos. A few suggestions as to the care of the dynamo, as well as its installation, may be of value; and one of the important points under this head is that the driving power should have characteristics of steadiness and regularity of speed, and should always be sufficient to drive the dynamo with its full load, besides doing the other work which it may be called upon to sustain. Unsatisfactory results are always obtained by attempting to run a dynamo on an overloaded engine.

Wooden bed-plates are supplied, when ordered, for all dynamos, except in the largest and direct-connected machines.

Most machines are fitted with a ratchet and screw bolt, so that they may be moved backward or forward on the bed-plate in a direction at right angles to the armature shaft. By this means the driving belt can be tightened or loosened at will, while the machine is in operation. Care should be taken in tightening the belt not to bind the bearings of the armature and force the oil from between the surfaces of the shaft and boxes. Such practice will inevitably cause heating of the bearings and consequent injury.

Machines are usually assembled, unless ordered otherwise, so that the armature revolves clock-wise when the observer faces the pulley end of the shaft. All bipolar dynamos, however, may be driven in either direction by reversing the brushes and changing field connections.

The machine is provided with a pulley of the proper size to transmit the power demanded, and a smaller one should not be substituted unless approval be obtained from the makers.

When driving from a countershaft, or when belted directly to the main shaft, a loose pulley or belt holder should be used, to admit of starting and stopping the dynamo while the shafting is running.

Belts. A thin double or heavy single belt should be used, about a half inch narrower than the face of the pulley on the dynamo. An endless belt, one without lacing, gives the greatest steadiness to the lights.

All bolts and nuts should be firmly screwed down. All nuts which form part of electrical connections should receive special attention.

The copper commutator brushes are carefully ground to fit the commutator, and they should be set in the holders so as to bear evenly upon its surface. On machines where two or more brushes are supported on one spindle, the brushes on the same side of the commutator must be set so that they touch the same segments in the same manner. The brushes on the other side of the commutator must be set to bear on the segments diametrically opposite. When the brushes are not so set it is impossible to run the machine without sparking. A convenient method of determining the proper bearing point for the brushes is to set the toe of one brush at the line of insulation, dividing two segments of the commutator; then count the dividing lines for one-half the way around the surface, and set the other brush or brushes at the line diametrically opposite the first. Thus, on the forty-four segment commutator, after setting the tip of one brush at a line of insulation, count around twenty-three lines, setting the other brush at the twenty-third line, thus bringing the tips directly opposite each other. The angle which the brushes form with the surface of the commutator should be carefully noted, and the brushes should not be allowed to wear so as to increase or decrease this angle. Careless handling of the machine is at once indicated by the brushes being worn either to a nearly square end, or to a long taper in which the forward wires of the brush far outrun the back or inside wires. Either condition will inevitably be attended with excessive wear of both commutator and brushes.

After copper brushes are set in contact with the commutator, the armature should never be rotated backward. If it is required to turn the armature back, raise the brushes from the commutator by the thumb screw on the holder provided for that purpose, before allowing such rotation. When starting a machine, it is always better to let the brushes down upon the commutator after the machine has started, rather than before, except when carbon brushes are used.

Bearings. See that the bearings of the machine are clean and free from grit, and that the oil reservoirs are filled with a good quality of lubricating oil. The oil reservoirs should always be examined before starting, and all loose grit removed. After starting the machine, the oil should be all drawn off at the end of each day's run for the first three or four days, after which it may be assumed that any remaining grit has been carried off with the oil, and it will only be necessary to add a little fresh oil once in seven or ten days.

Starting Up a Dynamo or Motor. Fill the oil reservoirs and see that the automatic oiling rings are free to move. In the case of dynamos fitted with oil cups, start the oil running at a moderate rate. Too little oil will result in heating and injury of the bearings, but, on the other hand, excessive lubrication is unnecessary, wasteful and sometimes productive of harm.

When the dynamo is ready to be started, place the driving belt on the pulley on the armature shaft, and then slip it from the loose pulley or belt holder on to the driving pulley on the countershaft. Tighten the belt by means of the ratchet on the bed-plate, just sufficiently to keep it from slipping. Care should be taken not to put more pressure than is necessary on new bearings; carelessness in this respect is often followed by heating of the boxes, and possible permanent injury.

The brushes may now be let down upon the commutator, and the magnets will be slowly energized. Move the brushes slowly backward or forward by means of the yoke handle until there is no sparking at the lower brushes. Clamp the yoke in this position. If the top brushes then spark, move them slightly, one at a time, forward or backward in the brush holder until their non-sparking point is found.

The spring pressure exerted upon the commutator brushes should be just sufficient to produce a good contact without causing cutting. If the brushes cut, the commutator must be smoothed by the use of sandpaper, not *emery cloth.*

The dynamo should run without load, at the speed given by the manufacturer, and this speed should be uniformly maintained under all conditions. In the case of incandescent dynamos, any increase of speed above that given, shortens the life of the lamps, while a variation below causes unsatisfactory lights.

Before the load is put on, the dynamo should be tested for polarity. This can be done by holding a small pocket compass near the field or pole piece. If the dynamo is connected to be run in multiple with another machine and happens to be polarized wrong, it can be given the right polarity by lifting the brushes from the commutator, closing the field switch and then closing the double-pole switch used to throw it in multiple with the other machine, which is supposed to be now running. After the current has been allowed to pass through the fields for a few moments, the double-pole switch can be thrown open, and if a test with the compass is again made the polarity will be found to be right, and the dynamo is ready to be started in the usual manner.

In starting for the first time a bipolar dynamo which is to be run in multiple with a spherical armature dynamo, the above instructions should always be followed.

If the dynamo is to be used in series with another on the three-wire system, and is found to be polarized wrong, it can be given the right polarity by making a temporary connection from the positive brush of the new machine to the positive brush of the machine already in operation; and also a temporary connection from negative brush to negative brush, having first raised the brushes from the commutator and closed the field switch. Keep this connection for a few minutes, then open the field switch and break the temporary connections.

Another test with the compass will show that the polarity of the machine is now correct, and the dynamo is ready to be started in the usual manner.

Assuming that the lamps and lines are all ready, the following precautions must be observed when starting the dynamo:

Be very careful that the brushes are properly set and diametrically opposite each other, as explained before.

Be sure that all connections are securely made, and all nuts on the connection boards firmly set.

In cases where two or more dynamos are connected in multiple by the use of the equalizing connection, care should be taken that the circuit wires from both positive brushes are connected to the same side of the main line, while those from the negative are connected to the other side.

A neat arrangement of the equalizing connection can be made by using triple-pole switches on the switchboard, instead of double-pole switches, and making the equalizing connections through the center pole of the switch, instead of running a cable direct from one dynamo to the other. This method is especially desirable where three or more dynamos are run in multiple.

When dynamos are connected in series, as in the cases where the three-wire system is in use, the leading wire from the positive brush of one machine is connected to the negative brush of the other. The other two brushes (negative and positive) are connected to the main wire on the outside of the system, while the third or center wire is connected to the conductor between the two dynamos.

Dust or Gritty Substances. All insulations should be carefully cleaned at least once a day.

If any of the connections of the machine become heated, examination will show that the metal surfaces are not clean or not in perfect contact. Avoid the use of water or ice on the bearings in case of accidental heating, as the water may get to the armature and injure the insulation.

The Commutator should be kept clean and allowed to polish or glaze itself while running. No oil is necessary, unless the brushes cut, and then only at the point of cutting. A cloth slightly greased with vaseline is best for the purpose. Never use sandpaper on the commutator without first lifting the brushes. Otherwise the grit will stick to the brushes and cut the commutator.

Brushes. Care should be taken to keep copper commutator brushes in good shape, and not to allow them to be worn out of square; that is, too much to one side, so that the end is not worn at right angles to the lateral edges.

When the machine is not running, the brushes should always be raised from the commutator. The brushes should be kept carefully cleaned, and no oil or dirt allowed to accumulate upon them. This can be done by washing them occasionally in benzine or in a hot solution of soda ash.

Manufacturers usually furnish a gauge, which should be used occasionally to test the wearing of the brushes. If they are found to be worn either too flat or too blunt, they should be filed in proper shape, or, better still, ground on a grindstone. Carbon brushes require less care. Spindles upon which the brush holders are arranged to slide should be cleaned with emery cloth often enough to prevent tarnishing or the collection of dirt, which might cause heating by impairing the electrical connection.

Brush holders that can be moved laterally on the spindle by which they are supported, should be so arranged that the top and bottom brushes will bear on different parts of the length of the commutator, for the purpose of distributing the wear more uniformly.

In case of a **hot box** the most natural thing to do is to shut the machine down, but this should never be done until the following alternatives have been tried and failed:

First—Lighten the load.

Second—Slacken the belt.

Third—Loosen the caps on the boxes a little.

Fourth—Put more oil in bearings.

Fifth—If all the above fail to remedy the heating, use a heavy lubricant, such as vaseline or cylinder oil. Should the heating then diminish, the shaft must be polished with crocus cloth and the boxes scraped at the end of the day.

Sixth—Under no conditions put ice upon the bearing, unless you are perfectly familiar with such a procedure.

Seventh—If it is absolutely necessary to shut down, get the belt off as soon as possible, keeping the machine revolving meanwhile in order to prevent sticking, and at the same time take off the caps of the bearings. Do not stop the flow of oil to the bearings. When the caps have been taken off, stop the machine and get the linings out immediately, and allow them to cool in the air. Do not throw the linings into cold water, as it is liable to spring them.

Scraping should be done only by an experienced person, otherwise the linings may be ruined. Polish the shaft with crocus cloth, or, if badly cut, file with a very fine file, and afterwards polish with crocus.

Wipe the shaft, as well as the boxes, very carefully, as perhaps grit has been the cause of the hot box. Inspect the bearings; see that they are in line, that the shaft has not been sprung, and that the oil collar does not bear against the box.

Oily Waste should be kept in approved metal cans (made entirely of metal, with legs raising them at least three inches above the floor and with self-closing covers), and removed daily.

A competent man should always be kept on duty where generators are operating.

THE INSTALLATION OF MOTORS.

All motors should be insulated on floors or base frames, which should be kept filled to prevent absorption of moisture; also they should be kept clean and dry. Where frame insulation is impracticable, the Inspection Department having jurisdiction may, in writing, permit its omission, in which case the frame should be permanently and effectively grounded.

A high-potential machine which on account of great weight or for other reasons cannot have its frame insulated, should be surrounded with an insulated platform. This may be of wood, mounted on insulating supports, and so arranged that a man must stand upon it in order to touch any part of the machine.

The leads or branch circuits should be designed to carry a current at least fifty per cent greater than that required by the rated capacity of the motor, to provide for the inevitable overloading of the motor at times, without over-fusing the wires.

The motor and resistance box should be protected by a cutout or circuit breaker, and controlled by a switch, the switch plainly indicating whether "on" or "off." Where one-fourth horse power or less is used on low-tension circuits a single-pole switch will be accepted. The switch and rheostat should be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

In connection with motors the use of circuit breakers, automatic starting boxes and automatic under-load switches is recommended, wherever it is possible to install them.

Motors should not be run in series, multiple, or multiple-series, except on constant-potential systems, and then only by special permission of the Inspection Department having jurisdiction.

Like generators, they should be covered with a waterproof cover when not in use, and if necessary, should be inclosed in an approved case.

Motors, when combined with ceiling fans, should be hung from insulated hooks, or there should be an insulator interposed between the motor and its support.

Every motor should be provided with a name-plate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute.

One rule at all times to be remembered in starting and stopping motors is, *Switch first, rheostat last,* which means, in starting, close the switch first, and then gradually cut out all resistance as the motor speeds up, and to stop the motor open the switch first and then cut in all the resistance of the rheostat which is in series with the motor armature.

When starting any new motor for the first time, see that the belt is removed from the pulley and the motor started with no load. Never keep the rheostat handle on any of its coils longer than a moment, as they are not designed to regulate the speed of the motor but to prevent too large a flow of current into the armature before the latter has attained its full speed.

Fig. 1 shows a rheostat which is designed to protect automatically the armature of a motor. The contact arm is fitted with a spring which constantly tends to throw the arm on the "off point" and open the circuit, but is prevented from so doing, while the motor is in operation, by the small electro-magnet, shown on the face of the rheostat, which consists of a low-resistance coil connected in series with the field winding of the motor. This magnet holds the contact arm of the rheostat in the position allowing the maximum working current to flow through the armature while it is in operation.

If, for any reason, the current supplied to the motor be momentarily cut off, the speed of the armature generates a counter current which also tends to hold the arm in position as long as there is any motion to the motor armature; but as soon as the armature ceases to revolve, all current ceases to flow through the electro-magnet, thereby releasing the rheostat handle, which flies back to the "off point," as shown in the illustration, and the motor armature is out of danger. Such a device is of great value where inexperienced men have to handle motors, and are unaware that the first thing to be done when a motor stops, for any reason whatever, is to open the circuit, and then cut in all the resistance in the rheostat to prevent too large an in-rush of current when the motor is started up again.

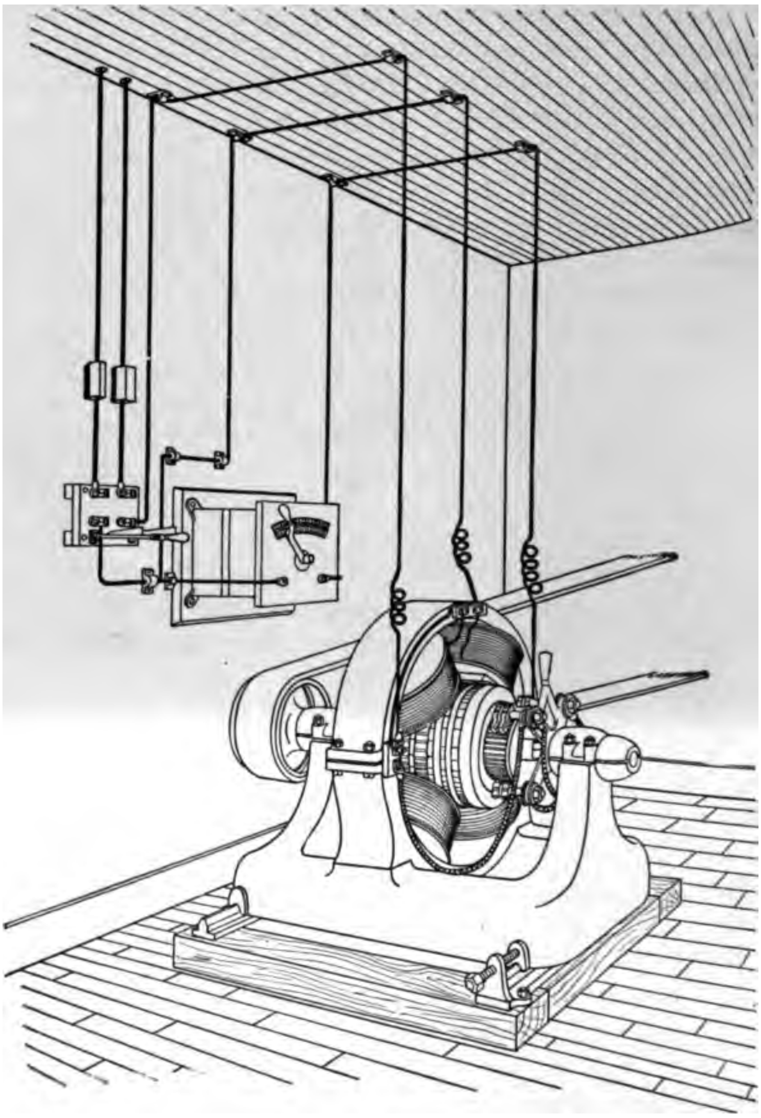


Fig. 1.

An approved installation in every detail; wiring connections for shunt-wound 4-pole motor, using double-pole fuse cut-out instead of circuit breaker.

The Circuit Breaker for under and over loads is also a most luable protection in such cases.

Motor Wiring Formulæ—(Direct Current). To find the ze of wire, in circular mils, required to transmit any power y distance at any required voltage and with any required loss, e have the following formula. Having found the required umber of circular mils, it is advisable to add 50 per cent more r safety.

e = potential of motor. d = distance from generator to motor.
v = volts lost in lines. K = efficiency of motor.
10.8 = resistance in ohms of 1 foot of 97 per cent pure copper wire one mil in diameter.

$$\text{c.m.} = \frac{\text{h. p. of motor} \times 746 \times 2d \times 10.8 \times 100}{e \times v \times K}$$

To find size of wire from c.m., see table, page 37.

AVERAGE MOTOR EFFICIENCY.

1 h. p.	75 per cent
3 h. p.	80 per cent
5 h. p.	80 per cent
10 h. p. and over	90 per cent

For Most Cases—(Small Installations). The table and exams worked out on pages 38, 39 and 40 will give the desired ults without the above formulæ.

To find current required by a motor when the horse power, ciency and voltage are known, use the following formula:

C = current to be found. H. P. = horse power of motor.
E = voltage of motor circuit. K = efficiency of motor.

$$C = \frac{\text{H. P.} \times 746 \times 100}{E \times K}$$

, when possible, use table I.

By adding the volts indicated in table II. to the voltage of lamp or motor, the result shows the voltage at the dynamo for ses indicated. Thus 10 per cent on 110-volt system is: 12.22 lts added to 110 equal 122.22, showing that the dynamo must nerate 122.22 volts for a 10 per cent loss.

TABLE I.

Amperes Per Motor.

H. P.	Per Cent.	Watts	THE TOP ROW INDICATES VOLTS.									
			50	75	110	220	400	500	600	800	1000	1200
¾	75	746	14.9	9.94	6.79	3.38	1.86	1.48	1.24	.93	.746	.62
1½	75	1492	29.8	19.8	13.56	6.78	3.73	2.98	2.48	1.86	1.492	1.24
3	80	2797	55.9	37.2	25.4	12.7	6.99	5.59	4.66	3.49	2.797	2.33
5	80	4662	93.2	62.1	42.3	21.1	11.65	9.32	7.77	5.82	4.662	3.88
7½	90	6217	124.	82.9	56.5	28.2	15.54	12.43	10.36	7.77	6.217	5.18
10	90	8288	165.	110.	75.5	37.6	20.72	16.57	13.81	10.36	8.288	6.90
15	90	12433	248.	165.	113.	56.5	31.08	24.86	20.72	15.53	12.43	10.36
20	90	16578	331.	221.	150.	75.3	41.44	33.15	27.63	20.72	16.57	13.98
25	90	20722	414.	276.	188.	94.1	51.8	41.6	34.5	25.9	20.7	17.2
30	90	24866	497	331.	226.	113.	62.	49.7	41.4	31.	24.8	20.7
40	90	33155	663.	442.	301.	150.	82.8	66.3	55.2	41.4	33.1	27.6
50	90	41444	828.	552.	376.	188.	103.	82.8	69.	51.8	41.4	34.5
60	90	49733	994.	663.	452.	226.	124.	99.4	82.8	62.	49.7	41.4
70	90	58022	1160.	773.	527.	263.	145.	116.	96.7	72.5	58.	48.3
80	90	66311	1326.	884.	602.	301.	165.	132.	110.	82.9	66.3	55.2
90	90	74599	1491.	994.	678.	339.	186.	149.	124.	93.	74.5	62.
100	90	82888	1657.	1105.	753.	376.	207.	165.	138.	103.	82.8	69.
120	90	99457	1989.	1326.	904.	452.	248.	198.	165.	124.	99.	82.8
150	90	124312	2486.	1657.	1131.	565.	310.	248.	207.	155.	124.	103.

TABLE II.

Volts Lost at Different Per Cent Drop.

Drop per cent.	VOLTAGE.											
	52	75	100	110	220	400	500	600	800	1000	1200	2000
½	.261	.376	.502	.552	1.10	2.01	2.51	3.01	4.02	5.02	6.03	10.05
1	.525	.757	1.01	1.11	2.22	4.04	5.05	6.06	8.08	10.10	12.12	20.2
1½	.2918	1.14	1.52	1.67	3.35	6.09	7.61	9.13	12.1	15.2	18.2	30.4
2	1.06	1.53	2.04	2.24	4.48	8.16	10.2	12.2	16.3	20.4	24.4	40.8
2½	1.33	1.92	2.56	2.82	5.64	10.25	12.8	15.3	20.5	25.6	30.7	51.2
3	1.61	2.31	3.09	3.40	6.80	12.37	15.4	18.5	24.7	30.9	37.1	61.8
4	2.16	3.12	4.16	4.58	9.16	16.66	20.8	24.9	33.3	41.6	49.9	83.3
5	2.73	3.94	5.26	5.78	11.57	21.05	26.3	31.5	42.1	52.6	63.1	105.
6	3.31	4.78	6.38	7.02	14.04	25.53	31.9	38.2	51.	63.8	76.5	127.
7	3.91	5.64	7.52	8.27	16.55	30.10	37.6	45.1	60.2	75.2	90.3	150.
8	4.52	6.52	8.69	9.56	19.13	34.78	43.4	52.1.	69.5	86.9	104.	173.
9	5.14	7.41	9.89	10.87	21.75	39.56	49.4	59.3	79.1	98.9	118.	197.
10	5.77	8.33	11.11	12.22	24.44	44.44	55.5	66.6	88.8	111.	133.	222.
11	6.42	9.26	12.35	13.59	27.19	49.43	61.7	74.1	98.8	123.	148.	247.
12	7.09	10.22	13.63	14.99	29.99	54.54	68.1	81.8	109.	136.	163.	272.
13	7.76	11.10	14.94	16.43	32.87	59.76	74.7	89.6	119.	149.	179.	298.
14	8.46	12.20	16.27	17.90	35.81	65.1	81.3	97.6	130.	162.	195.	325.
15	9.17	13.23	17.64	19.41	38.82	70.5	88.2	105.	141.	176.	211.	352.
20	13.	18.75	25.	27.50	55.	100.	125.	150.	200.	250.	300.	400.
25	17.33	25.	33.33	36.66	73.33	133.	166.	200.	266.	333.	400.	666.

OUTSIDE WIRING AND CONSTRUCTION.

Service Wires (those leading from the outside main wire to the buildings and attached to same) should be "Rubber-Covered."

Line Wires, other than service wires, should have an approved "weatherproof covering."

Bare Wires may be used through uninhabited and isolated territories free from all other wires, as in such places wire covering would be of little use, as it is not relied on for pole insulation, and is not needed for other purposes, because the permanent insulation of the wires from the ground is assured by the glass or porcelain petticoat insulators to which the wires are secured.

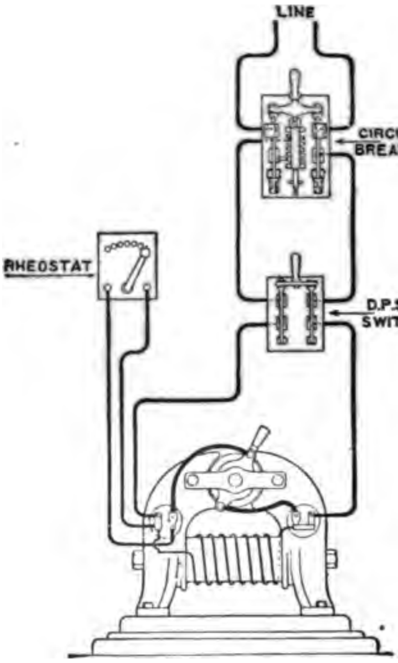


Fig. 2.

An approved installation in every detail; wiring connections for shunt-wound bipolar motor, using circuit breaker instead of double-pole fuse cut-out.

Tie Wires should have an insulation equal to that of the conductors they confine.

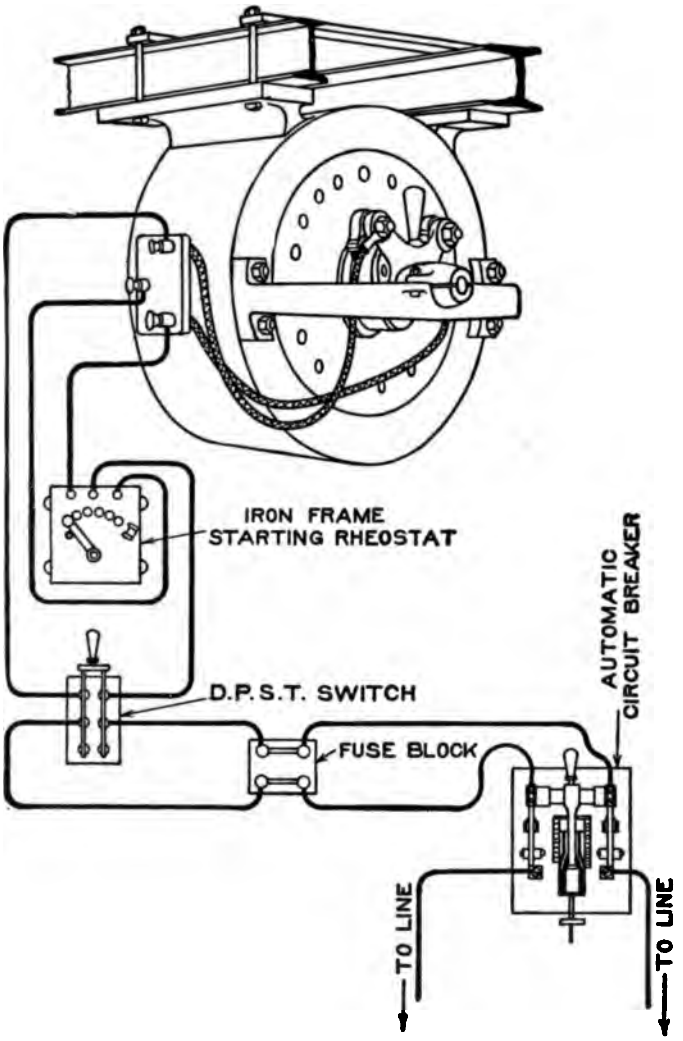


Fig. 3.

An approved installation in every detail, with wiring connections for shunt-ound multipolar slow speed ceiling motor for direct connection to line shaft. sing both circuit breaker and double-pole fuse cut-out.

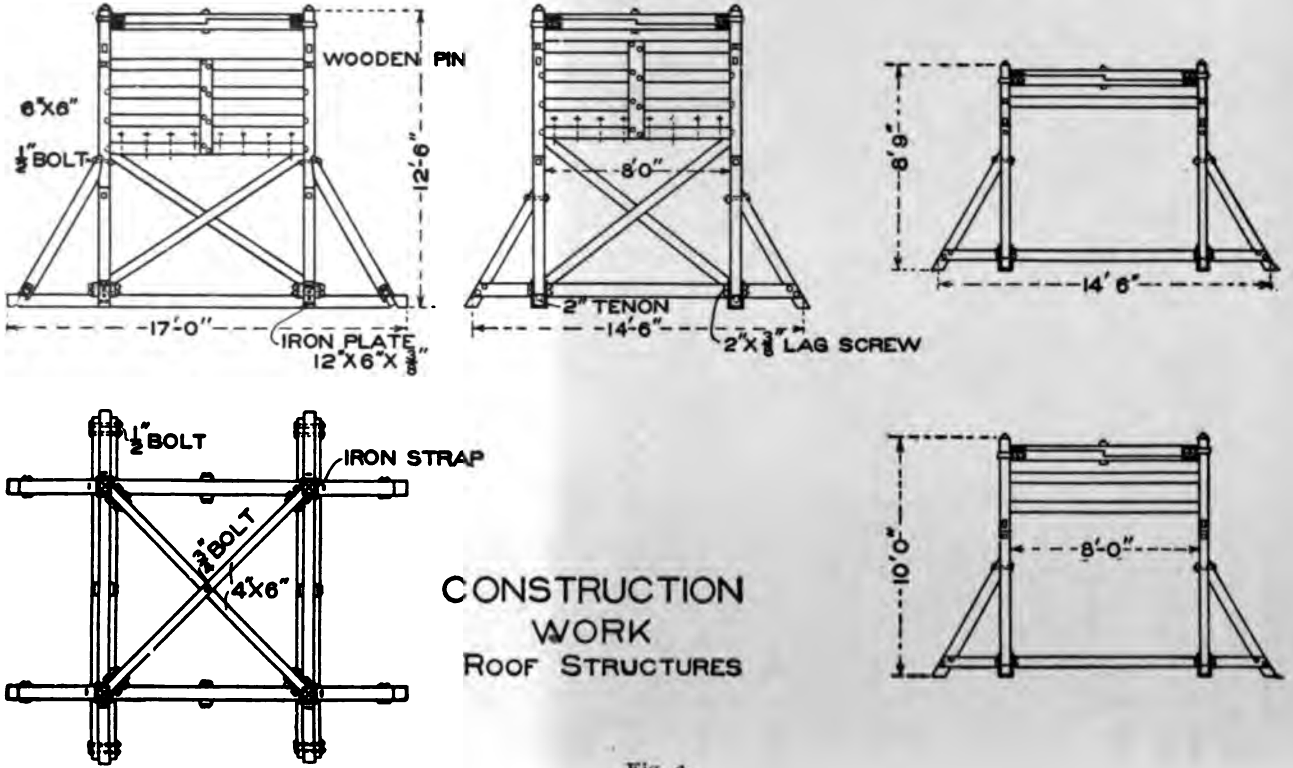

WOODEN PIN
6"X6"
1/2" BOLT
12'-6"
-17'-0"-
IRON PLATE 12"X6"X 3/8"
-8'0"-
2" TENON
-14'-6"-
2"X 3/8" LAG SCREW
8'9"
-14' 6"-
1/2" BOLT
IRON STRAP
3/4" BOLT
4"X6"
10'0"
-8'-0"-
CONSTRUCTION
WORK
ROOF STRUCTURES

Fig. 4.

Space Between Wires for outside work, whether for high or low tension, should be at least one foot, and care should be exercised to prevent any possibility of a cross connection by water. Wires should never come in contact with anything except their insulators.

Roof Structures. If it should become necessary to run wires over a building, the wires should be supported on racks which will raise them seven feet above flat roofs or at least one foot above the ridge of pitched roofs. See Fig. 4.

Guard Arms. Whenever sharp corners are turned, each cross arm should be provided with a dead insulated guard arm to prevent the wires from dropping down and creating trouble, should their insulating support give way.

Petticoat Insulators should be used exclusively for all outside work, and especially on cross arms, racks, roof structures and service blocks. Porcelain knobs, cleats or rubber hooks should never be used for this heavy outside work.

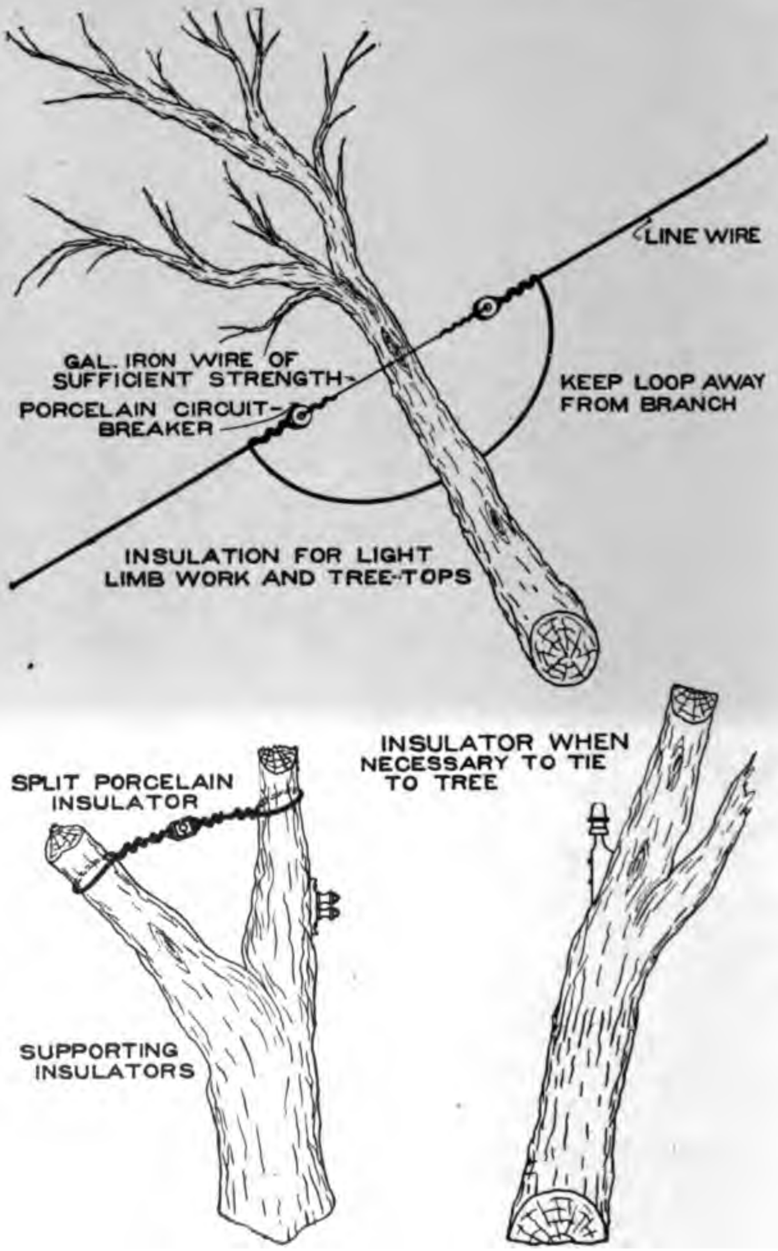
Splicing of two pieces of wire or cable should be done in such manner as to be mechanically and electrically secure without solder. The joints should then be soldered to prevent corrosion and consequent bad contact. All joints thus made should be covered with an insulation equal to that of the conductors.

Tree Wiring. Whenever a line passes through the branches of trees, it should be properly supported by insulators, as shown in Fig. 5, to prevent the chafing of the wire insulation and grounding the circuit.

Service Blocks which are attached to buildings should have at least two coats of waterproof paint to prevent the absorption of moisture.

Entrance Wires. Where the service wires enter a building they should have drip loops outside, and the holes through which the conductors pass should be bushed with non-combustible, non-absorptive insulating tubes slanting upward toward the inside. See Fig. 6.

Telegraph and Telephone wires should never be placed on the same cross-arm with light or power wires, especially when alternating currents are used, as trouble will arise from induc-



LINE WIRE
GAL. IRON WIRE OF SUFFICIENT STRENGTH
PORCELAIN CIRCUIT-BREAKER
KEEP LOOP AWAY FROM BRANCH
INSULATION FOR LIGHT LIMB WORK AND TREE-TOPS
SPLIT PORCELAIN INSULATOR
INSULATOR WHEN NECESSARY TO TIE TO TREE
SUPPORTING INSULATORS

Fig. 5.

tion, unless expensive special construction, such as the transposing of the lighting circuits, be resorted to at regular intervals. Even under these conditions it is bad practice, as an accidental contact with the lighting or power circuit might result in starting a fire in the building to which the telephone line is connected. If, however, it is necessary to place telegraph or telephone wires on the same poles with lighting or power wires, the distance between the two inside pins of each cross-arm should not be less than twenty-six inches, and the metallic sheaths to cables should be thoroughly and permanently connected to earth.

Transformers should not be placed inside of any buildings except central stations, and should not be attached to the outside walls of buildings, unless separated therefrom by substantial supports.

In cases where it is impossible to exclude the transformer and primary wiring from entering the building, the transformer should be located as near as possible to the point where the primary wires enter the building, and should be placed in a vault or room constructed of or lined with fire-resisting material, and containing nothing but the transformer. In every case the transformer must be insulated from the ground and the room kept well ventilated. It is of course the safest and best practice to place all transformers on poles away from the building that is to be lighted, as illustrated in Fig. 7.

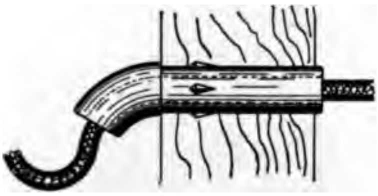


Fig. 6.
Porcelain tube, used where wires enter buildings, showing drip loop in wire.

The Grounding of Low-Potential Circuits is allowed only when such circuits are so arranged that under normal conditions of service there will be no passage of current over the ground wire.

In Direct-Current 3-Wire Systems the neutral wires may be grounded, and when grounded the following rules should be complied with:

1. They should be grounded at the central station on a metal plate buried in coke beneath permanent moisture level, and

also through all available underground water and gas pipe systems.

2. In underground systems the neutral wire should also be grounded at each distributing box through the box.

3. In overhead systems the neutral wire should be grounded every 500 feet.

When grounding the neutral point of transformers or the neutral wire of distributing systems the following rule should be complied with:

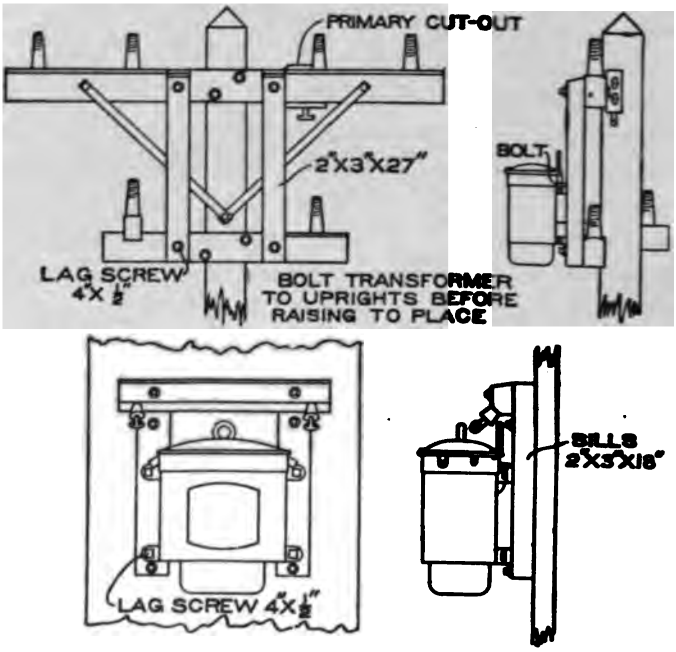


Fig. 7.
Construction work; installing transformers.

1. Transformers feeding two-wire systems should be grounded at the center of the secondary coils, and when feeding systems with a neutral wire, should have the neutral wire grounded at the transformer, and at least every 500 feet for underground systems.

In making ground connections on low-potential circuits, the ground wire in direct-current 3-wire systems should not at central stations be smaller than the neutral wire, and not smaller than No. 6 B. & S. elsewhere.

In Alternating-Current Systems the ground wire should never be less than No. 6 B. & S., and should always have equal carrying capacity to the secondary lead of the transformer, or the combined leads where transformers are banked.

These wires should be kept outside of buildings, but may be directly attached to the building or pole, and should be carried in as nearly a straight line as possible, all kinks, coils and sharp bends being avoided.

The ground connection for central stations, transformer substations, and banks of transformers should be made through metal plates buried in coke below permanent moisture level, and connection should also be made to all available underground piping systems, including the lead sheath of underground cables.

For individual transformers and building services the ground connection may be made to water or other piping systems running into the buildings. This connection may be made by carrying the ground wire into the cellar and connecting on the street side of meters, main cocks, etc., but connection should never be made to any lead pipes which form part of gas services.

In connecting ground wires to piping systems, wherever possible, the wires should be soldered into one or more brass plugs and the plugs forcibly screwed into a pipe fitting, or, where the pipe is cast iron, into a hole tapped into the pipe itself. For large stations, where connecting to underground pipes with bell and spigot joints, it is well to connect to several lengths, as the pipe joints may be of rather high resistance. Where such plugs cannot be used, the surface of the pipe may be filed or scraped bright, the wire wound around it, and a strong clamp put over the wire and firmly bolted together.

Where ground plates are used, a No. 16 copper plate, about 3 by 6 feet in size, with about two feet of crushed coke or charcoal, about pea size, both under and over it, would make a ground of sufficient capacity for a moderate-sized station, and would probably answer for the ordinary sub-station or bank of transformers. For a large central station considerable more area might be neces-

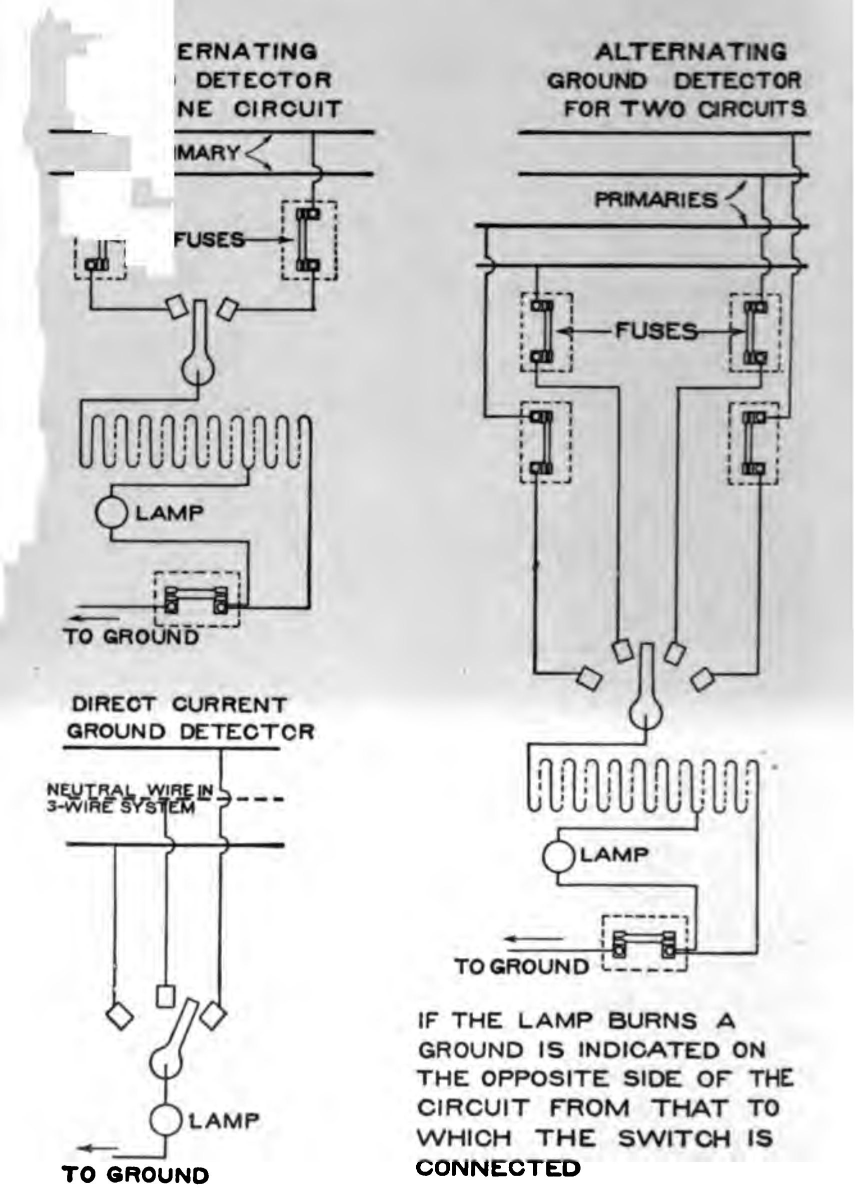


Fig. 8.
Connections of Ground Detectors.

sary, depending upon the underground connections available. The ground wire should be riveted to such a plate in a number of places, and soldered for its whole length. Perhaps even better than a copper plate is a cast iron plate, brass plugs being screwed into the plate to which the wire is soldered. In all cases, the joint between the plate and the ground wire should be thoroughly protected against corrosion, by suitable painting with waterproof paint or some equivalent.

Ground Detectors. Fig. 8 illustrates a few practical methods of detecting grounds on alternating and direct-current circuits which have not been purposely grounded.

In using any one of these methods for detecting grounds, always see that the circuit to ground is left open after testing the outside circuits.

Some central station men are in the habit of leaving the ground circuit closed on one side constantly in order that any ground that might occur on the other side may be instantly noticed. This, however, is bad practice, as it greatly reduces the insulation of the whole system. Test all circuits at least once a day.

It is sometimes necessary to know just what the insulation resistance of a line, or of the wiring in a building, is in ohms. This can be found very readily, and closely enough for all practical purposes, by using a Weston volt meter in the following manner:

Connect with a wire from one side of the circuit to one binding post of the volt meter, and with another piece of wire connect a water pipe to the other binding post of the volt meter. If the needle or pointer shows any deflection we know there is a ground, or leakage, on the opposite side of the circuit to which the volt meter is connected.

The resistance of this ground leak may be found by the following formula:

$R = r(\frac{V}{v} - 1)$ ohms when R = resistance of ground leak required, r = resistance of volt meter, V = voltage between the positive and negative sides of the line, v = reading in volts, on the instrument, produced by the leakage.

Primary Wiring. Primary wires should be kept at least ten inches apart, and at that distance from conducting material. Primary wires carrying over 3,500 volts should not be brought into or over any building other than the central power station or sub-station.

Wires for Outside Use have in most cases a "weatherproof" insulation, except service wires, which should be "rubber-covered." Any insulating covering for wires exposed to the weather on poles is in a short time rendered useless. The real insulation of the system will be found to be dependent upon the porcelain or glass insulators.

POLES FOR LIGHT AND POWER WIRES.

It is essential to a proper installation that the poles receive due consideration, a fact that is too often overlooked.

In selecting the style of pole necessary for a certain class of work the conditions and circumstances should be considered. Poles may be arranged in three classes, the size of wire which they are to carry respectively being one of the important regulating circumstances.

First Class: Alternating-current plants for lighting small towns. Main line of poles should consist of poles from 30 to 35 feet long, with 6-inch tops. These are strong enough for all the weight that is placed upon them. No pole less than 30 feet with 6-inch top should be placed on a corner for lamps. The height of trees, of course, must be considered in many cases. For the Edison municipal system, where more than one set of wires are used for street lighting, a 6-inch top should be the size of the poles, the length being not less than 30 feet, and greater than this if the streets be hilly and filled with trees.

Second Class: Town lighting by arc lights. All poles should be at least 6-inch tops. The corner poles should be 6½-inch tops; and wherever the cross-arms are placed on a pole at different angles, the pole should be at least a 6½-inch top. A 30-foot pole is sufficiently long for the main line, but it would be advisable to place 35-foot poles on corners.

Third Class: Where heavy wire, such as No. 00, is used for feeder wire, the poles should be at least 7-inch tops. Where mains are run on the same pole line the strain is somewhat lessened, and poles of smaller size will answer all purposes.

Cull Poles. The question as to what is a cull pole is something on which many authorities differ. Of course, if specifications call for a certain sized pole, parties supplying the poles should be compelled to send the sizes called for. All poles that are smaller at the top than the sizes agreed upon, are troubled with dry rot, large knots and bumps, have more than one bend, or have a sweep of over twelve inches, should certainly be classed as cull poles. Specifications for electric light and power work should be, and in many cases are, much more severe than those required by telegraph lines. A cull pole, one of good material, is the best thing for a guy stub, and is frequently used for this purpose. A cedar pole is always preferable to any other, owing to the fact that it is very light compared with other timber, and is strong, durable and very long lived.

Pole Setting. It seems to be the universal opinion of the best construction men that a pole should be set at least five feet in the ground, and six inches additional for every five feet above thirty-five feet. Also additional depths on corners. Wherever there is much moisture in the ground, it is well to paint the butt end of the pole, or smear it with pitch or tar, allowing this to extend about two feet above the level of the ground. This protects the pole from rot at the base. The weakest part of the pole is just where it enters the ground. Never set poles farther than 125 feet apart; 110 feet is good practice.

Pole Holes should be dug large enough so that the butt of the pole can be dropped straight in without any forcing, and when the pole is in position only one shovel should be used to fill in, the earth being thoroughly tamped down with iron tampers at every step until the hole is completely filled with solidly packed earth. Where the ground is too soft for proper tamping, a grouting composed of one part of Portland cement to two parts of sand, mixed with broken stone, may be used to make an artificial foundation.

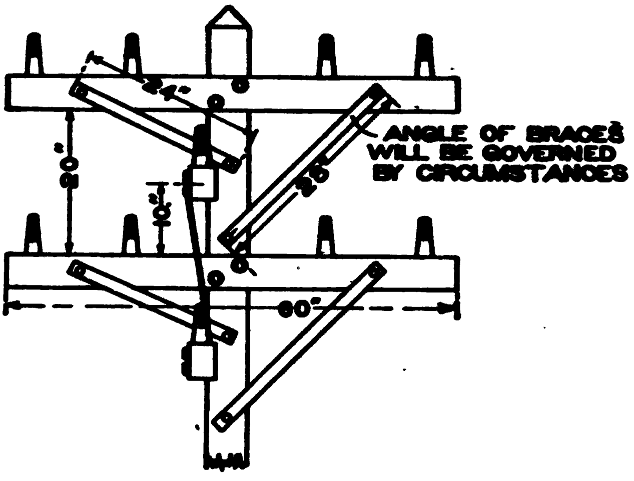


FIG. 1

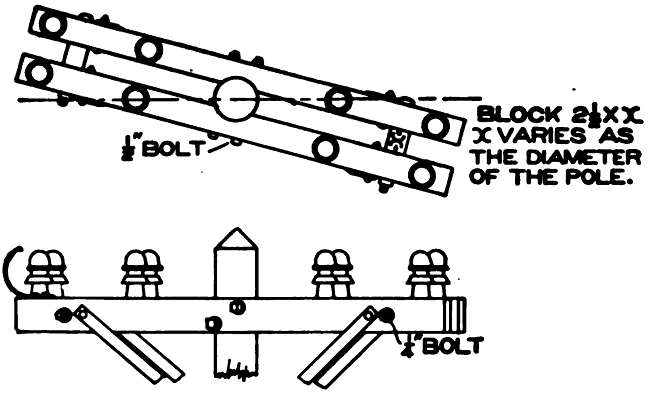


FIG. 2

Fig. 9.

CONSTRUCTION WORK; POSITION OF CROSS-ARMS WHEN TURNING CORNERS.

When running a heavy line wire it is necessary to use two cross-arms fastened as shown above in Fig. 2. If lines are not heavy, only one cross-arm will be necessary. In case lines cross the street diagonally, the arms where the wires leave and those to which they run are both set at an angle. When turning an abrupt corner only one arm is turned. The above cannot be used where feeders tap into double branches. In such a case the method given in Fig. 1 is used.

TABLE III.

Cedar Poles for Electric Light Work.

SIZE.	Average weight, pounds each.	No. of Poles to a Car.	SIZE.	Average weight, pounds each.	No. of Poles to a Car.
25 ft., 5-inch top	200	150	35 ft., 7-inch top	650	90
25 " 5½ " "	225	130	40 " 6 " "	800	80
25 " 6 " "	250	120	40 " 7 " "	900	75
28 " 7 " "	400	80	45 " 6 " "	900	70
30 " 5 " "	300	110	45 " 7 " "	1000	65
30 " 6 " "	350	90	50 " 6 " "	1200	55
30 " 7 " "	420	75	55 " 6 " "	1400	45
35 " 6 " "	550	100			

Painting. When poles are to be painted, a dark olive green color should be chosen, in order that they may be as inconspicuous as possible. One coat of paint should be applied before the pole is set, and one after the pole is set. Tops should be pointed to shed water.

All poles 35 feet long and over must be loaded on two cars.

For chestnut poles add 50 per cent to weights as given in table.

Cross-Arms. The distance from the top of the pole to the cross-arm should be equal to the diameter of pole at the top. All cross-arms should be well painted with one coat of paint before placing, and must be of standard size as shown in the diagrams. Cross-arms of four or more pins should be braced, using one or two braces as occasion demands. Cross-arms on one pole should face those on the next, thereby making the cross-arms on every other pole face in one direction. All pins should have their shanks dipped in paint and should be driven into the cross-arm while the paint is wet. The upper part of the pin should also be painted. Iron pins may be furnished for corners where there is a heavy strain, but are not advised, it being preferable to use the construction as shown in the diagrams. Put double arms on the pole where feeder wires end.

Guard Irons. Guard irons should be placed at all angles in lines, and on break-arms.

Steps. All junction and lamp poles should be stepped so that the distance between steps on the same side of the pole will not be over 36 inches. Poles carrying converters should also be stepped.

TABLE IV.

Pole Line Data.

Gauge Number (B. & S.)		4/0	3/0	2/0	1/0	1	2	3	4	5	6	7	8
Diam. of Bare Wire, in Thousandths		.460	.40964	.3648	.3249	.2893	.2576	.2294	.2043	.1819	.1620	.1442	.1285
Ohms Res. B. Wire per Mile, 75° Fahr.		.25902	.32667	.41188	.5499	.6910	.8719	1.099	1.400	1.754	2.213	2.812	3.539
Wt. (lbs.) per 1000 feet Insulated Wire		826	611	460	357	300	244	204	168	119	100	84	71
Weight per Mile (approximate) of Insulated Wire		4360	3225	2225	1880	1580	1285	1075	885	625	525	440	373
No. of Poles per Lineal Mile.	Distance Between Poles (feet).	Approximate Weight of Insulated Wire Between Poles.											
20	264.00	218.0	161.3	121.3	94.0	79.0	64.25	53.75	44.25	31.2	26.25	22.	18.65
21	251.40	208.0	153.6	115.5	89.53	75.0	61.2	51.2	42.2	30.0	25.0	20.96	17.8
22	240.10	198.2	146.6	110.3	85.5	71.9	58.5	48.9	40.3	28.41	23.9	20.0	16.96
23	229.56	189.69	140.3	105.5	81.74	68.70	55.88	46.8	38.5	27.17	22.83	19.2	16.22
24	220.00	181.7	134.4	101.0	78.34	65.84	53.54	44.8	36.91	26.05	21.9	18.34	15.55
25	211.20	174.4	129.	97.0	75.20	63.2	51.40	53.0	35.4	25.0	21.0	17.6	14.92
26	203.07	167.7	124.04	93.3	72.40	60.8	49.42	41.34	34.04	24.04	20.19	16.93	14.35
27	195.55	161.5	119.5	89.81	69.63	58.52	47.22	40.00	32.77	23.15	19.45	16.30	13.82
28	188.55	155.7	115.2	86.61	67.50	56.43	45.90	38.39	31.61	22.33	18.76	15.72	13.33
29	182.09	150.34	111.3	83.62	64.82	54.48	44.31	37.07	30.52	21.56	18.11	15.18	12.87
30	176.00	145.34	107.5	80.85	62.67	52.67	42.84	35.84	29.50	20.86	17.50	14.67	12.44
31	170.30	140.65	104.04	78.23	60.65	50.97	41.46	34.68	28.55	20.17	16.94	14.20	12.04
32	165.00	136.25	100.80	75.80	58.75	49.38	40.16	33.60	27.66	19.54	16.41	13.75	11.72
33	160.00	132.13	97.73	73.49	56.97	47.88	38.94	32.58	26.82	18.94	15.91	13.34	11.31
34	155.29	128.24	94.86	71.83	55.30	46.48	37.80	31.62	26.03	18.39	15.45	12.95	10.98
35	150.85	124.58	92.15	69.29	53.72	45.15	36.73	30.72	25.29	17.86	15.00	12.58	10.66
36	146.66	121.12	89.59	67.37	52.23	43.89	35.70	29.87	24.59	17.37	14.59	12.23	10.37
37	142.70	117.84	87.17	65.55	50.82	42.71	34.73	29.06	23.92	16.90	14.19	11.90	10.09
38	138.96	114.74	84.87	63.82	49.48	41.58	33.82	28.29	23.29	16.45	13.82	11.58	9.82
39	135.38	111.80	82.69	62.20	48.21	40.52	32.95	27.57	22.69	16.03	13.47	11.29	9.57
40	132.00	109.00	80.63	60.63	47.00	39.50	32.13	26.88	22.13	15.63	13.13	11.00	9.33
41	128.78	106.35	78.66	59.15	45.86	38.58	31.35	26.22	21.60	15.25	12.81	10.74	9.10
42	125.71	103.81	76.79	57.74	44.77	37.62	30.60	25.60	21.08	14.90	12.50	10.48	8.89
43	122.79	101.40	75.00	56.40	43.73	36.75	29.90	25.00	20.50	14.54	12.21	10.24	8.68
44	120.00	99.10	73.30	55.12	42.73	35.91	29.21	24.44	20.12	14.21	11.94	10.00	8.48
45	117.33	96.89	71.67	53.90	41.80	35.12	28.56	23.90	19.67	13.90	11.67	9.78	8.30
46	114.78	94.79	70.11	52.72	40.88	34.35	27.94	23.37	19.24	13.59	11.42	9.57	8.11
47	112.34	92.77	68.62	51.60	40.00	33.62	27.35	22.90	18.83	13.30	11.18	9.37	7.94
48	110.00	90.84	67.20	50.52	39.17	32.92	26.78	22.40	18.44	13.03	10.94	9.17	7.78
49	107.75	88.99	65.82	49.49	38.36	32.25	26.03	21.94	18.07	12.77	10.72	8.98	7.63
50	105.60	87.20	64.50	48.50	37.60	31.60	25.70	21.50	17.70	12.50	10.50	8.80	7.46
51	103.52	85.50	63.24	47.55	36.97	31.00	25.20	21.09	17.36	12.26	10.30	8.63	7.32
52	101.53	83.85	62.02	46.64	36.16	30.39	24.75	20.68	17.02	12.02	10.10	8.47	7.18
53	99.64	82.27	60.86	45.76	35.48	29.82	24.25	20.29	16.70	11.80	9.92	8.31	7.04
54	97.77	80.75	59.73	44.91	34.82	29.26	23.80	19.91	16.40	11.58	9.73	8.15	6.91
55	96.00	79.28	58.64	44.10	34.19	28.73	23.37	19.55	16.10	11.37	9.55	8.00	6.78

Guys. All poles at angles in the line must be properly guyed, using No. 4 B. & S. galvanized iron wire, or two No. 8 wires twisted. All junction poles should also be guyed. Never attach a guy wire to a pole so that it prevents a cross-arm from being removed.

For alternating work, double petticoat insulators are recommended. Pole brackets, except in connection with the tree insulators, should not be used.

Tape should be secured at either end of a joint by a few turns of twine. When looping for lamps, etc., leave coiled sufficient wire, without waste, to reach lamp or building without joints. In cutting arc or incandescent lamps into an existing circuit, use a piece of "rubber-covered" wire. Feeder wires should be strung on the cross-arms above the mains.

For good distribution, arc lamps should not be placed more than 800 feet apart. The lamps may be brought nearer together if a greater degree of illumination is desired.

Primary Wires on Poles. When running more than one circuit of primaries upon the same line of poles the wires of each circuit should be run parallel and on adjacent pins, as shown below, so as to avoid any fluctuation in the lamps due to induction. The lines lettered A and A are for circuit No. 1, and B and B for circuit No. 2, etc.

..............................A
..............................A
..............................B
..............................B

When connecting transformers to 1,000-volt mains a double-pole cut-out is placed in the primary circuit. For 2,000-volt circuits a single-pole cut-out should be placed in each side of the line, thus avoiding any possible short circuit due to an arc being established across the contacts of the double-pole cut-out. This, owing to the greater difference of potential between opposite poles, is liable to occur when the fuses "blow."

INSIDE WIRING.

Approved "Rubber-Covered" Wire should be used exclusively in all interior wiring. Although the Fire Underwriters allow "Slow Burning" weatherproof wire to be used in dry places when wiring is entirely exposed to view and rigidly supported on porcelain or glass insulators, "Rubber-Covered" wire is always preferable.

The copper conductors, before being rubber-covered, should be thoroughly tinned, and the thickness of the rubber covering should conform to the following table:

TABLE V.

Requisite Thickness of Rubber Covering for Wires.

For voltages up to 600:

From No.	18	to No.	16	inclusive,	$\frac{1}{32}$ in.
"	14	to "	8	"	$\frac{3}{64}$ in.
"	7	to "	2	"	$\frac{1}{16}$ in.
"	1	to "	0000	"	$\frac{5}{64}$ in.
"	0000	to "	500000 c. m.	"	$\frac{3}{32}$ in.
"	500000 c. m.	to "	1000000 "	"	$\frac{7}{64}$ in.
Larger than		"	1000000 "	"	$\frac{1}{8}$ in.

For voltages between 600 and 3,500:

From No. 14	to No.	1	inclusive,	$\frac{3}{32}$ in.	
" 0	to "	500000 c. m.	"	$\frac{3}{32}$ in.	covered by braid or tape.
Larger than		500000 "	"	$\frac{3}{32}$ in.	

"Slow Burning Weatherproof" Wire should have an insulation consisting of two coatings, the inner one to be fireproof in character and the other to be weatherproof. The inner fireproof coating should comprise at least six-tenths of the total thickness of the wall.

The complete covering should be of a thickness not less than that given in the following table:

TABLE VI.

Requisite Thickness of Slow Burning Weatherproof Insulation.

From No.	14	to No.	8	inclusive,	$\frac{3}{64}$ in.
"	7	to "	2	"	$\frac{1}{16}$ in.
"	2	to "	0000	"	$\frac{5}{64}$ in.
"	0000	to "	500000 c. m.	"	$\frac{3}{32}$ in.
"	500000 c. m.	to "	1000000 "	"	$\frac{7}{64}$ in.
Larger than		"	1000000 "	"	$\frac{1}{8}$ in.

"Weatherproof" Wire, for out-door use, should consist of at least three braids thoroughly impregnated with a dense moisture-repellant which should stand a temperature of 180° Fahrenheit without dripping. The thickness should correspond to that of "Slow Burning Weatherproof" and the outer surface should be thoroughly slicked down.

Carrying Capacity of Wires. Table VII gives the safe carrying capacity of wires from No. 18 B. & S. to cables of 2,000,000 circular mils.

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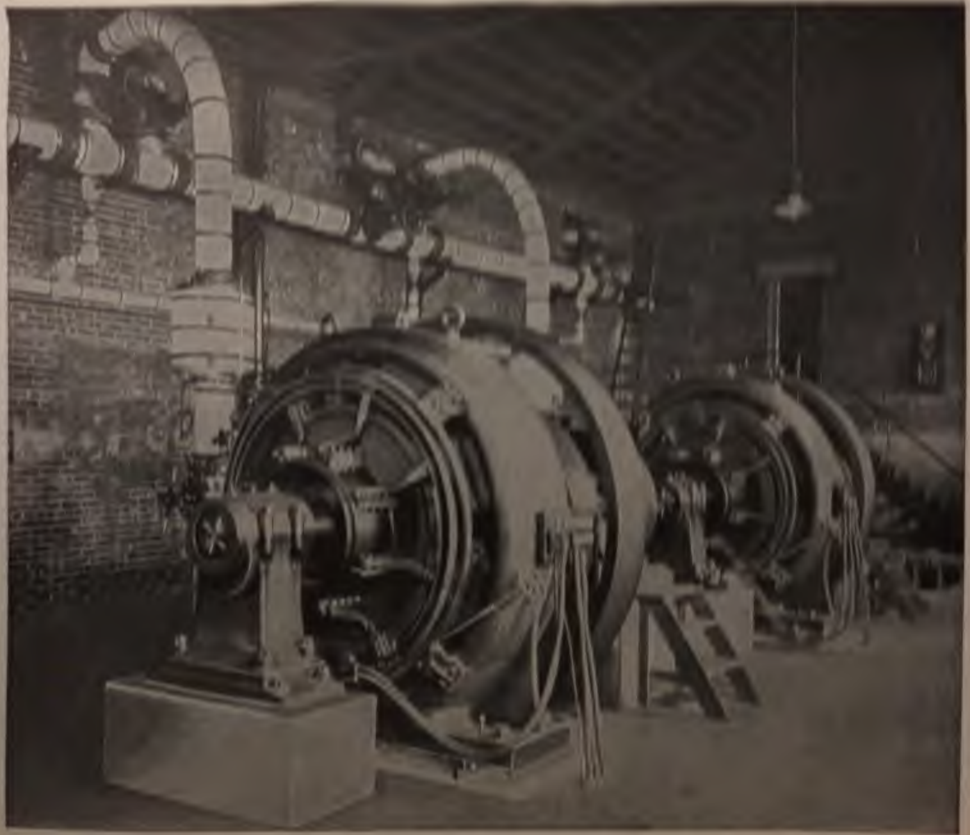


DIRECT-CONNECTED GENERATORS
Operating the Largest Woodworking Plant in the United States.
Triumph Electric Company.

No wires smaller than No. 14 should be used except for fixture wiring and pendants, in which cases as small as No. 18 may be used.

TABLE VII.

Safe Carrying Capacity of Wires.

Gauge No. B. & S. Diameter Mils. Area Circular Mils. No. Amperes Open Work. No. Amperes Concealed Work. Ohms Per 1000 Ft. Lbs. per 1000 Ft. Bare. Lbs. Per 1000 Ft. Insulated. No. and Size of Wires for Cables.

Gauge No. B. & S.	Diameter, Mils.	Area, Circular Mils.	No. Amperes, Open Work.	No. Amperes, Concealed Work.	Ohms per 1000 Ft.	Lbs. per 1000 Ft. Bare.	Lbs. per 1000 Ft. Insulated.	No. and Size of Wires for Cables.
18...	40	1,624	5	3	6.3880	4.92	18	
17...	45	2 048	6	4	5.0660	6.20	21	
16...	51	2,583	8	6	4.0176	7.82	25	
15...	57	3,257	10	8	3.1860	9.86	31	
14...	64	4,106	16	12	2.5266	12.44	38	
13...	72	5,178	19	14	2.0037	15.68	43	
12...	81	6,530	23	17	1.5890	19.77	48	
11...	91	8,234	27	21	1.2602	24.93	64	
10...	102	10,380	32	25	.99948	31.44	80	
9...	114	13,090	39	29	.79242	39.65	97	
8...	128	16,510	46	33	.62849	49.99	116	
7...	144	20,820	56	39	.49845	63.03	118	
6...	162	26,250	65	45	.39528	79.49	166	
5...	182	33,100	77	53	.31346	100.23	196	
4...	204	41,740	92	63	.24858	126.40	228	
3...	229	52,630	110	75	.19714	159.38	265	
2...	258	66,370	131	88	.15633	200.98	296	
1...	289	83,690	156	105	.12398	253.43	329	
0...	325	105,500	185	125	.09827	319.74	421	
00...	365	133,100	220	150	.07797	402.97	528	
000...	410	167,800	262	181	.06134	508.12	643	
0000...	460	211,600	312	218	.04904	640,73	815	
Cables.	630	300,000	405	273	.03355	932.	Weight of insulations on cables varies for different kinds of work.	37-090
" .	727.3	400,000	503	332	.02516	1242.		37-1039
" .	814.5	500,000	595	390	.02013	1553.		61-0905
" .	891.9	600,000	682	440	.01666	1863.		61-0991
" .	963.9	700,000	765	488	.01438	2174.		61-1071
" .	1030.5	800,000	846	540	.01258	2474.		61-1145
" .	1092.6	900,000	924	585	.01118	2795.		61 1214
" .	1152.	1,000,000	1000	630	.01006	3106.		61-128
" .	1208.7	1 100,000	1075	675	.00915	3416.		61-1343
" .	1262.8	1,200,000	1147	715	.00838	3727.		91-1148
" .	1314.5	1,300,000	1217	755	.00769	4038.		91-1195
" .	1364.	1,400,000	1287	795	.00715	4348.		91-124
" .	1413.5	1,500,000	1356	835	.00667	4658.		91-1285
" .	1458.6	1,600,000	1423	875	.00625	4968.		91-1326
" .	1503.7	1 700,000	1489	910	.00588	5278.		91-1367
" .	1547.7	1,800 000	1554	945	.00556	5588.		127-1195
" .	1571.9	1,900,000	1618	980	.00527	5898.		127-1223
" .	1630.2	2,000,000	1681	1015	.00500	6208.		127-1254

Tie Wires should have an insulation equal to that of the conductors they confine.

Splicing should be done in such manner as to make the wires mechanically and electrically secure without solder; then they should be soldered to insure preservation from corrosion and from consequent heating due to poor contact.

Stranded Wires should have their tips soldered before being fastened under clamps or binding screws. When the stranded wires have a conductivity greater than No. 10 B. & S. copper wire, they should be soldered into lugs. All joints should be soldered in preference to using any kind of splicing device.

Wiring Table. The following examples show the method of using the table on page [illegible]:

1. What size of wire should we use to run 50 16-candle-power lamps on 110 volts a distance of 150 feet to the center of distribution with the loss of 2 volts?

First multiply the amperes, which will be 25.5 (50 16-c.p. 110-volt lamps take 25.5 amperes, see table on page 57), by the distance, 150 feet, which will equal 3,825 ampere feet. Then refer to the columns headed "Actual Volts Lost"; and as we are to have a loss of two volts only, look down the column headed 2 until we come to the nearest corresponding number to 3,825, and we find that 4,000 is the best number to use. Put your pencil on the number 4,000 and follow that horizontal column to the left until you come to the vertical column headed "Size B. & S.," and we find that a No. 4 B. & S. wire will be the proper size to use in this case.

2. [illegible] should we use to carry current for a [illegible] and is situated 200 [illegible] point, the drop in volts not to exceed [illegible]

[illegible] amperes by 200 feet, as we did in the first [illegible] ampere feet. Now look at the upper [illegible] and you will see a vertical column [illegible] this column until you come to 220. [illegible] the right until you come to the [illegible] can come to a 2 per cent loss [illegible] Place your pencil on the figure [illegible] vertical column of figures until you come to the nearest corresponding figure to [illegible], which we find to be [illegible]. Then with the pencil on this figure follow the horizontal column to the left, and we find that a No. 5 B. & S. wire is a proper size to use for the above conditions.

3. Supposing we have occasion to inspect a piece of wiring, and find a dynamo operating 50 16-c. p. 110-volt lamps at a distance of 150 feet, and our wire gauge shows that wire in use is a No. 12 B. & S., at what loss, or "drop," are these lamps being operated?

First multiply the amperes, which will be 25.5 (50 16-c. p. 110-v. lamps take 25.5 amperes, see table on page 57), by the distance, 150 feet, and we get 3,825 ampere feet. As we find in use a No. 12 B. & S. wire, we look for the vertical column headed "Size B. & S." and follow it down until we come to 12. With our pencil on the figure 12 we travel along the horizontal line to the right until we come to the nearest corresponding number to 3,825, which we find to be 4,575. Then starting at this number we travel up the vertical column and we find a loss of about 15 actual volts, or, practically, a 12 per cent loss, which would greatly reduce the candle-power or brilliancy of the lamps.

Installation of Wires. All wiring should be kept free from contact with gas, water or other metallic piping, or with any other conductors or conducting material which it may cross, by some continuous and firmly fixed non-conductor, creating a separation of at least one inch. In wet places it should be arranged so that an air space will be left between conductors and pipes in crossing, and the former must be run in such a way that they cannot come in contact with the pipe accidentally.

Wires should be run over rather than under pipes upon which moisture is likely to gather, or which by leaking might cause trouble on a circuit. No smaller size than No. 14 B. & S. gauge should ever be used for any lighting or power work, not that it may not be electrically large enough, but on account of its mechanical weakness and liability to be stretched or broken in the ordinary course of usage. Smaller wire may be used for fixture work, if provided with approved rubber insulation.

Wires should never be laid in or come in contact with plaster, cement, or any finish, and should never be fastened by staples, even temporarily, but always supported on porcelain cleats which will separate the wires at least one-half inch from the surface wired over and keep the wires not less than two and one-half

TABLE VIII.

Wiring for Light and Power Circuits.

To find size of wire, multiply current in amperes by single distance and refer to the nearest corresponding number under column of Actual Volts Lost.

Volts.							Percentage of Loss										
2000	1.7	1.5	1.4	1.2	1.1	1.0	0.75	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05
1000	3.4	2.9	2.7	2.4	2.2	2.0	1.5	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
500	6.5	5.7	5.2	4.8	4.3	3.9	2.9	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2
220	13.7	12.0	11.0	10.3	9.3	8.3	6.5	4.4	3.9	3.5	3.1	2.7	2.2	1.8	1.4	0.9	0.45
110			20.0	18.5	17.0	15.4	12.0	8.4	7.6	6.8	6.0	5.2	4.4	3.5	2.7	1.8	0.9
52							22.4	16.1	14.7	13.3	11.8	10.3	8.8	7.1	5.5	3.7	1.9

Actual Volts Lost.

*Carrying Capacity, Amperes	Size B. & S	35	30	27.5	25	22.5	20	15	10	9	8	7	6	5	4	3	2	1
300	0000	345800	296400	271700	247000	222300	197600	148200	98800	88920	79040	69160	59280	49400	39520	29640	19760	9880
245	000	274400	235200	215600	196000	176400	156800	117600	78400	70560	62720	54880	47040	39200	31360	23520	15680	7840
215	00	217525	186450	170912	155375	139837	124300	93225	62150	55935	49720	43505	37290	31075	24860	18645	12430	6215
190	0	172550	147900	135575	123250	110925	98600	73950	49300	44370	39440	34510	29580	24650	19720	14790	9860	4930
160	1	136850	117300	107525	97750	87975	78200	58650	39100	35190	31280	27370	23460	19550	15640	11730	7820	3910
135	2	108500	93000	85250	77500	69750	62000	46500	31000	27900	24800	21700	18600	15500	12400	9300	6200	3100
115	3	86100	73800	67650	61500	55350	49200	36900	24600	22140	19680	17220	14760	12300	9840	7380	4920	2460
100	4	68250	58500	53625	48750	43875	39000	29250	19500	17550	15600	13650	11700	9750	7800	5850	3900	1950
90	5	54250	46500	42625	38750	34875	31000	23250	15500	13950	12400	10850	9300	7750	6200	4650	3100	1550
80	6	43050	36900	33825	30750	27675	24600	18450	12300	11070	9840	8610	7380	6150	4920	3690	2460	1230
60	8	26985	23130	21202	19275	17347	15420	11565	7710	6939	6168	5397	4626	3855	3084	2313	1542	771
40	10	16975	14550	13337	12125	10912	9700	7275	4850	4365	3880	3395	2910	2425	1940	1455	970	485
30	12	10675	9150	8388	7625	6862	6100	4575	3050	2745	2440	2135	1830	1525	1220	915	610	305
22	14	6720	5760	5280	4800	4320	3840	2880	1920	1728	1536	1344	1152	960	768	576	384	192
15	16	4235	3630	3328	3025	2723	2420	1815	1210	1089	968	847	726	605	484	363	242	121

*Note. In case a larger loss than any given in the table is required, proceed as follows: **Divide the ampere feet by 10, and then refer to column Actual Volts Lost divided by 10, from which we find the size wire as before.**

inches apart. Three-wire cleats may be used when the neutral wire is run in the center and at least two and one-half inches separate the two outside or + and — wires. This style of wiring is intended for low-voltage systems (300 volts or less); and when it is all open work, rubber-covered wire is not necessary, as "weatherproof" wire may be used. Weatherproof wire should not be used in moulding. Wires should not be fished between floors, walls or partitions, or in concealed places, for any great distance, and only in places where the inspector can satisfy himself that the rules have been complied with, as this style of work is always more or less uncertain.

Twin wires should never be used, except in conduits or when flexible conductors are necessary; they are always unsafe for light or power circuits on account of the short distance between them.

All wiring should be protected on side walls from mechanical injury. This may be done by putting a substantial boxing about the wires, allowing an air space of one inch around the conductors, closed at the top (the wire passing through bushed holes) and extending about five feet above the floor. Sections of iron-armored conduit may be used, and in most cases are preferable, as they take up but little room and are very rigid.

If, however, iron pipes are used with alternating currents, the two or more wires of a circuit should always be placed in the same conduit. If plain iron pipe be used the insulation of that portion of each wire within the pipe should be reinforced by a tough conduit tubing projecting beyond the iron tubing at both ends about two inches.

When crossing floor timbers in cellars or in rooms where they might be exposed to injury, wires should be attached, by their insulating supports, to the under side of wooden strips not less than one-half inch in thickness and not less than three inches wide.

GENERAL FORMULÆ FOR LIGHT AND POWER WIRING.

c. m.=circular mils.

d = length of wire, in feet, on one side of circuit.

n = number of lamps in multiple.

TABLE IX.

Dimensions and Resistances of Copper Wire.

Gauge. No.	Diam. Mils.	Area, Circ. Mils. B. and S. Gauge.	BARE WIRE.			WEATHERPROOF WIRE.			*Safe Carrying Capacity, Cur. in Amp.	Ohms per 1000 ft.	Ohms per Mile.	Feet per Ohm.	Area C. M. B. W. G.
			Lbs. per 1000 ft.	Lbs. per. Mile.	Ft. per Pound.	Lbs. per 1000 ft.	Lbs. per Mile.	Ft. per Pound.					
0000	460.	211600.	640.73	3383.04	1.56	800	4224.	1.25	312	[illegible]04	.25891	20392.9	206100
000	410.	167800.	508.12	2682.85	1.97	666	3516.	1.50	262	[illegible]84	.32649	16172.1	180600
00	365.	133100.	402.97	2127.66	2.48	500	2640.	2.00	220	[illegible]97	.41168	12825.4	144400
0	325.	105600.	319.74	1688.20	3.13	363	1917.	2.75	185	[illegible]27	.51885	10176.4	115600
1	289.	83690.	253.43	1338.10	3.95	313	1653.	3.20	156	[illegible]98	.65460	8066.0	90000
2	258.	66370.	200.98	1061.17	4.98	250	1320.	4.00	131	[illegible]33	.82543	6396.7	80660
3	229.	52630.	159.38	841.50	6.28	200	1056.	5.00	110	[illegible]14	1.04090	5072.5	67080
4	204.	41740.	126.40	667.38	7.91	144	760.	6.9	92	[illegible]58	1.31248	4022.9	56640
5	182.	33100.	100.23	529.23	9.98	125	660.	8.0	77	[illegible]46	1.65507	3190.2	48400
6	162.	26250.	79.49	419.69	12.58	105	554.	9.5	65	[illegible]28	2.08706	2529.9	41210
7	144.	20820.	63.03	332.82	15.86	87	364.	11.5		.49845	2.63184	2006.2	32400
8	128.	16510.	49.99	263.96	20.00	69	301.	14.5	46	.62849	3.31843	1591.1	27230
9	114.	13090.	39.65	209.35	25.22					.79242	4.18400	1262.0	21900
10	102.	10380.	31.44	165.98	31.81	50	264.	20.0	32	.99948	5.27726	1000.5	17960
11	91.	8234.	24.9	131.65	40.11					1.2602	5.65357	793.56	14400
12	81.	6530.	19.77	104.40	50.58	31	164.	32.0	23	1.5890	8.39001	629.32	11810
13	72.	5178.	15.68	82.792	63.78					2.0037	10.5798	499.06	9025
14	64.	4106.	12.44	65.658	80.42	22	116.	45.0	16	2.5266	13.3405	395.79	6889
15	57.	3257.	9.86	52.069	101.40					3.1860	16.8223	313.87	5184
16	51.	2583.	7.82	41.292	127.87	14	74.	70.0	8	4.0176	21.2130	248.90	4225
17	45.	2048.	6.20	32.746	161.24					5.0660	26.7485	197.39	3364
18	40.	1624.	4.92	25.970	203.31	11	58.	90.0	5	6.3880	33.7285	156.54	2400
19	36.	1288.	3.90	20.594	256.39					8.0555	42.5329	124.14	1764
20	32.	1021.	3.09	16.331	323.32					10.1584	53.6362	98.44	1230

*Safe carrying capacity of exposed wire. Carrying capacity of wire enclosed in moulding is about 40 per cent less. See table on page 37 fifth column.

Approximate weight of weatherproof line wire is 10% less than the weight of underwriters' wire as given above.

c = current in amperes per lamp.
v = volts lost in lines.
r = resistance per foot of wire to be used.

10.8 ohms resistance of one foot of commercial copper wire having a diameter of one mil and a temperature of 75° Fahrenheit.

It is an easy matter to find any of the above values by the following formulæ:

$$c.m. = \frac{10.8 \times 2d \times n \times c}{v}$$

$$v = \frac{10.8 \times 2d \times n \times c}{c.m.} \qquad c = \frac{c.m. \times v}{10.8 \times 2d \times n}$$

$$n = \frac{c.m \times v}{10.8 \times 2d \times c} \qquad 2d = \frac{c.m. \times v}{10.8 \times c \times n}$$

$$r = \frac{v}{n \times c \times 2d}$$

$$v = n \times c \times 2d \times r \qquad c = \frac{v}{2d \times n \times r}$$

$$n = \frac{v}{c \times 2d \times r} \qquad 2d = \frac{v}{n \times c \times r}$$

Arc Light Wiring. All wiring in buildings for constant-current series arc lighting should be with approved rubber-covered wire, and the circuit arranged to enter and leave the building through an approved double-contact service switch, which means a switch mounted on a non-combustible, non-absorptive insulating base and capable of closing the main circuit and disconnecting the branch wires when turned "off." This switch must be so constructed that it will be automatic in action, not stopping between points when started, must prevent an arc between points under all circumstances, and must indicate, upon inspection, whether the current is "on" or "off." Such a switch is necessary to cut the high voltage completely out of the building by firemen in case of fire or when it becomes necessary to make any changes in the lamps or wiring.

This class of wiring should never be concealed or encased except when requested by the Electrical Inspector, and should always be rigidly supported on porcelain or glass insulators which will separate the wiring at least one inch from the surface wired over, and which must be kept at least four inches from each other on all voltages up to 750, and eight inches apart when the voltages exceed 750. No wires carrying a voltage of over 3,500 should be carried into or over any buildings except central stations and sub-stations. All arc light wiring should be protected on side walls and when crossing floor timbers where wires are liable to injury. In mill-construction buildings, arc wires of No. 8 and larger, where not liable to be disturbed, may be separated six inches for voltages up to 750, and ten inches for voltages above 750; may run from timber to timber, not breaking round; and may be supported at each timber only. In running along beams or walls and ceilings they should be supported at intervals not exceeding four and one-half feet.

SPECIAL WIRING.

Special wiring for damp places such as breweries, packing houses, stables, dye houses, paper or pulp mills, or buildings especially liable to moisture or acid or other fumes likely to injure the wires or their insulation, should be done with approved rubber-covered wire, and rigidly supported on porcelain or glass insulators which separate the wires at least one inch from the surface wired over, and which must be kept apart at least two and one-half inches. The wire in such damp places should contain no splices, as it is almost impossible to tape a splice that will prevent acid fumes from getting at the copper surface.

Moulding Work should always be done with approved rubber covered wire to prevent leakage should the moulding become damp.

This class of work should never be done in concealed or damp places, for fear that water may soak into the wood and cause leakage of current between the wires, burning the wood and starting a fire. The action of the current in a case like this is to convert the wood very gradually into charcoal, then dry the water out and ignite the charcoal thus formed. Great care should be observed in driving nails into moulding, to avoid puncturing the insulation and possibly grounding the circuit in a way that not only might be difficult to locate, but might cause a concealed fire back of the plastering or wood work to which the moulding is attached.

Moulding should be of hard wood and made of two pieces, a backing and capping, so constructed as to thoroughly encase the wire. It should provide a one-half inch tongue between the conductors and a solid backing, which under the grooves should be not less than three-eighths of an inch in thickness and able to give suitable protection from abrasion.

Concealed Wiring or that which is to be run between walls and floors and their joists, should always be done with approved rubber-covered wire, and should be rigidly supported on porcelain or glass insulators which will separate the wires at least one inch from the surface wired over. The wires should be kept at least ten inches apart, and where it is possible should be run singly on separate timbers or joists. The insulators should be placed not farther than four feet apart in any case, and where there is any liability of the wires coming in contact with anything else, due to a possible sagging, the supports should be placed much closer together. In some cases where it is impossible to rigidly support the wiring on porcelain or glass insulators in concealed places, the wires, if not exposed to moisture, may be fished on the loop system if encased throughout in approved continuous flexible tubing or conduit. Fishing under floors or between walls is done by boring holes at suitable distances apart and pushing a flat spring wire from one hole toward the other and catching it with a wire hook. The flexible conduit and wires may then be pulled into place.

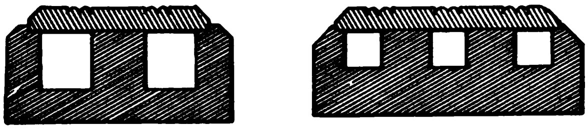


Fig. 10.

Samples of approved moulding when filled and covered with at least two coats of waterproof paint.

Although this fished work may be passed when the surrounding conditions are, at the time of inspection, perfectly satisfactory, it should be avoided, as trouble will arise in this class of work sooner than in any other, when all conditions are equal.

Insulated Metal Conduits — (Specifications). The metal covering or pipe should be of sufficient thickness to resist penetration by nails, etc., or the same thickness as ordinary gas pipe of the same size.

It should not be seriously affected externally by burning out a wire inside the tube when the iron pipe is connected to one side of the circuit.

The insulating lining should be firmly attached to the pipe, and should not crack or break when a length of conduit is uniformly bent at a temperature of 212 degrees Fahrenheit, to an angle of 90 degrees, with a curve having a radius of 15 inches, for pipes of 1 inch or less, or a radius of fifteen times the diameter of the pipe for larger sizes.

The insulating lining should not soften injuriously at a temperature below 212 degrees Fahrenheit, and should leave water in which it has been boiled, practically neutral.

The insulating lining should be at least one-thirty-second of an inch in thickness; and the materials of which it is composed should be of such a nature as will not have a deteriorating effect on the insulation of the conductor, and be sufficiently tough and tenacious to withstand the abrasion test of drawing in and out of some long lengths of conductors.

The insulating lining should not be mechanically weak after three days' submersion in water, and, when removed from the pipe entire, should not absorb more than ten per cent of its weight of water during 100 hours of submersion.

All elbows should be made for the purpose, and not bent from lengths of pipe. The radius of the curve of the inner edge of any elbow should not be less than three and one-half inches.

There should not be more than the equivalent of four quarter bends from outlet to outlet, the bends at outlets not being counted.

Each length of conduit, whether insulated or uninsulated, should have the maker's name or initials stamped in the metal or attached to it in some satisfactory manner, so that it may be readily seen, thus rendering it possible to place the responsibility for pieces not up to standard.

Uninsulated Metal Conduits or plain iron or steel pipes may be used instead of the insulated metal conduits, if made equally as strong and thick as the ordinary form of gas pipe of the same size, provided their interior surfaces are smooth and free from burrs. To prevent oxidation, the pipe should be galvanized, or the inner surfaces coated or enameled with some substance which will not soften so as to become sticky and prevent the wire from being withdrawn from the pipe. Elbows must be made for the purpose, and not bent from lengths of pipe. The radius of curves and number of bends from outlet to outlet should be the same as given under Insulated Metal Conduits. This bare iron or steel pipe should never contain any but a special extra insulated wire as hereinafter described:

Conduit Wire for Insulated Metal Conduits, whether single or twin conductors, should be standard rubber-covered wire as described on page 35; and where concentric wire is used in insulated metal conduits, it should have a braided covering between the outer conductor and the insulation of the inner conductor, and in addition should comply with and be able to withstand the test of standard rubber-covered wire.

Conduit Wire for Uninsulated Metal Conduits should not only have a standard rubber insulation as required for Insulated Metal Conduits, but in addition should have a second outer fibrous covering at least one-thirty-second inch in thickness, and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit. When concentric conductors are to be used in uninsulated metal conduits, they not only should comply with the requirements when used in insulated metal conduits, but, in addition, should have a second outer fibrous covering at least one-thirty-second of an inch in thickness and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit.

Interior Conduit Installation. All conduits should be continuous from one junction box to another or to fixtures, and the conduit tube should properly enter all fittings, otherwise the conductors are not perfectly protected, and water is much more liable to gain an entrance into the conduit. No conduit with an inside diameter of less than five-eighths inch should be used.

The entire conduit system for a building should be completely installed before a single wire is drawn in; and all ends of conduits should extend at least one-half inch beyond the finished surface of walls or ceilings, except that, if the end is threaded and a coupling screwed on, the conduit may be left flush with the surface, and the coupling may be removed when work on the building is completed.

After all conductors have been drawn or pushed in, all outlets should be plugged up with special wood or fibrous plugs made in parts to fit around the wire, and the outlet then sealed with a good compound to keep out all moisture. All joints should be made air-tight and moisture-proof.

The metal of every conduit system should be effectually and permanently grounded. The conduit is likely to be more or less grounded, and a positive ground is necessary for the same reason that a positive ground is required for generator frames when it is impossible to insulate them perfectly.

Conduit Wiring. The reason why standard rubber covered wire, and not weatherproof, should be used in conduits, is that the best possible insulation is desirable for this class of work, as the insulating lining of the conduit may be defective in places, and there is a possibility of dampness getting into the conduit.

No wires should be drawn in until all mechanical work on the building is done.

Wires of different circuits should not be drawn in the same conduit.

For alternating systems, the two or more wires of a circuit should be drawn in the same conduit, in order to avoid trouble from inductive losses, which, under certain conditions, would cause a heating of the iron conduit to a dangerous degree. This trouble from induction becomes very much less if the wires are in the same conduit; less still, if the wires are twisted together; and disappears almost entirely if concentric wire is used.

Even in direct-current work it is advisable to place the two ires of a circuit in the same conduit, as in so doing the direct rrent may be changed for the alternating current without the ecessity of rewiring, which would be necessary if only a single ire were placed in a conduit.

Fixtures, when supported from the gas piping of a build- g, should be insulated from the gas-pipe system by means of pproved insulating joints placed as close as possible to the ceiling, nd the wires near the gas pipe above the insulating joint should e protected from possible contact by the use of porcelain tubes.

All burrs or fins should be removed from the fixtures before he wires are drawn in. The tendency to condensation within he pipes should be guarded against by sealing the upper end of he fixture.

In combination fixtures, where the wiring is concealed etween the inside pipe and outer casing, the space between pipe nd casing should be at least a quarter of an inch to allow plenty f room for the insulation of the wires without jamming.

Fixtures should be tested for "contacts" between conductors nd fixtures, for "short circuits" and for ground connections, be- ore being connected to the supply conductors.

Ceiling blocks of fixtures should be made of insulating aterial; if not, the wires in passing through the plate should be rrounded by porcelain tubes.

Rosettes. These fittings should not be located where inflam- able flyings or dust will accumulate on them. Bases should be igh enough to keep the wires and terminals at least one-half inch rom the surface to which the rosette is attached.

Terminals with a turned up lug to hold the wire or cord ould be used, and in no case must the wire be cut or injured. used rosettes are not advised for use where cords can be properly rotected by line cut-outs. If fused rosettes are used, the next ses back should not be over 25 amperes capacity.

Fixture Wiring should be done with fixture wire, which has solid insulation with a slow-burning, tough, outer covering, the hole at least one-thirty-second of an inch in thickness, and ving an insulation resistance between conductors, and between either conductor and the ground, of at least one megohm per mile, after one week's submersion in water at 70 degrees Fahrenheit, and after three minutes' electrification with 550 volts.

Although No. 18 (B. & S. gauge) is allowable in fixture work, it is never advisable to use smaller than No. 16, for mechanical reasons. Supply conductors, and especially the splices to fixture wires, should be kept clear of the grounded part of gas pipes, and where shells are used the latter should have area enough to prevent pressing the wires against the gas pipe when finally in place. Where fixtures are wired on the outside, it is advisable to use cord for attaching the wires to the fixture, and not short bits of wire, as the latter might produce a short circuit or ground.

Flexible Cord should be made of a number of copper strands; no single strand should be larger than No. 26 or smaller than No. 30 (B. & S. gauge), and each conductor should be covered by an approved insulation and be protected from mechanical injury by a tough, braided, outer covering. When used for pendant lamps it should hang freely in air and be so placed that there is no chance of its coming in contact with anything excepting the lamp socket to which it is attached and the rosette from which it hangs. Each stranded conductor should have a carrying capacity equivalent to not less than a No. 18 (B. & S. gauge) wire. The covering of the stranded wires for flexible cord should first have a tight, close wind of fine cotton, which is intended to prevent any broken strand from piercing the insulation and causing a short circuit or ground. Secondly, it should have a solid waterproof insulation at least one-thirty-second of an inch thick, and should show an insulation resistance of 50 megohms per mile throughout two weeks' submersion in water at 70 degrees Fahrenheit. The outer protecting braiding should be so put on and sealed in place that when cut it will not fray out.

Flexible cord should not be used as a support for clusters, as it is not strong enough, and it should never be used for anything other than pendants, wiring of fixtures and portable lamps, portable motors, or small, light electrical apparatus.

Flexible cord should never be used in show windows, as a fective piece might cause a short circuit and set fire to flimsy ıterial or decorations. Many fires have been caused by the use flexible cord in show windows, where handkerchiefs, decora- ıns, etc., have been pinned to the cord. When the current is urned on" short circuits are caused by the pins, and a fire is ɜ result.

Insulating bushings should be used where cords enter lamp ːkets and desk stand lamps.

Flexible cord should be so suspended that the entire weight the socket, lamp and shade will be borne by knots under the shing in the socket, and above the point where ɜ cord comes through the ceiling block or sette, in order that the strain may be taken ɔm the joints and binding screws. It is good actice always to solder the ends of flexible rds which are going under binding screws, as holds the strands together and prevents the essure of the screws from forcing the strands ɔm under them and against the shell of the ːket, causing a grounded shell or short circuit.

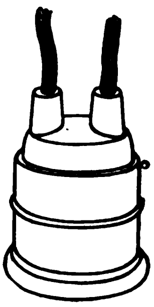


Fig. 11.
Waterproof keyless socket, to be used in dye houses or damp places.

Where it becomes necessary to solder a ɜat number of ends, as may be required when ring a factory, use a small pot of melted der and dip the ends of the wire, which have all been previously t to the proper length.

Standard Lamp Sockets should be plainly marked 50 candle- wer, 250 volts, and with either the manufacturer's name or ɡistered trade mark. The inside of the shell of the socket ɔuld have an insulating lining which should absolutely prevent ɜ shell from becoming part of the circuit, even though a wire or 'and inside the socket should become loose or come out from der a binding screw. This insulating lining should be at least e-thirty-second of an inch thick and of a tough and tenacious ıterial.

Special Lamp Sockets. In rooms where inflammable gases ıy exist, both the socket and lamp should be enclosed in a vapor- ·ht globe, supported on a pipe-hanger, and wired with "Rubber-covered wire soldered directly in the circuit. No fuses or switches of any sort should be used in such cases, as the slightest arc might produce dangerous explosions or fires. See Fig. 11.

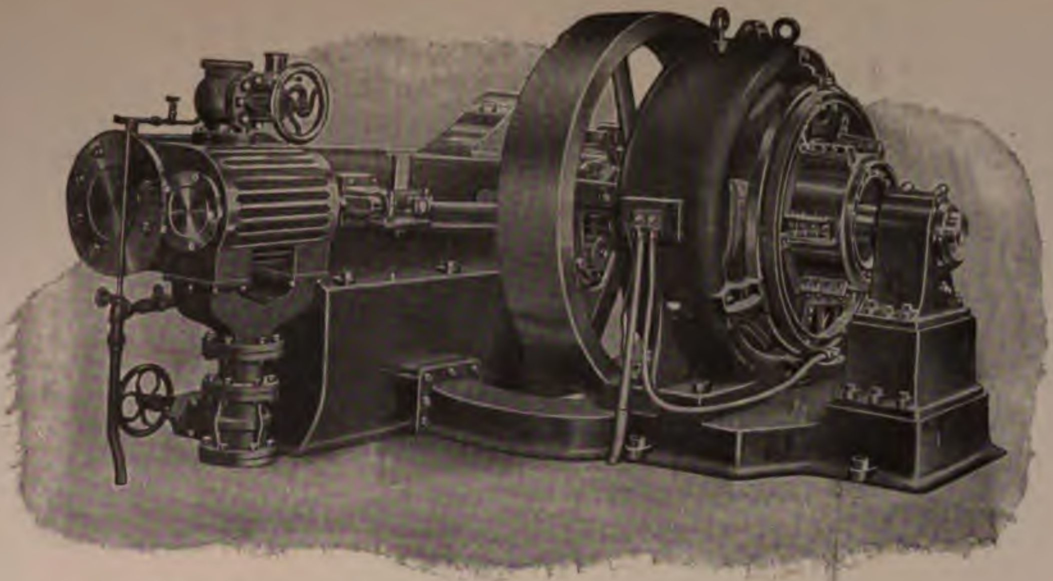
In damp or wet places, such as dye houses, breweries, etc., a vaporproof socket such as shown on page 31 should be used. Vaporproof sockets should be hung by separate stranded rubber-covered wires, not smaller than No. 14 (B & S.). These wires should be soldered direct to the circuit wires, but supported independently of them. All sockets for the above conditions should be keyless.

Stranded Wires in every case should be soldered together before being clamped under binding screws, and when they have a conductivity greater than No. 10 (B & S.) copper wire they should be soldered into lugs. Stranded wires if not thus stiffened before being clamped under binding posts, are liable to be pressed out or easily worked loose, making a poor contact, which causes heating, a possibility of arcing or a complete burn out, or fusing of the wire at this point.

Bushings. All wires should be protected when passing through walls, partitions or floors, by non-combustible, non-absorptive insulating tubes, such as glass or porcelain. Each bushing should be long enough to go clear through and allow a projection of at least a quarter of an inch on both ends. Bushings should be long enough to bush the entire length of the hole in one continuous piece, or else the hole should first be bushed by a continuous waterproof tube, which may be a conductor, such as iron pipe, and the tube then should have a non-conducting bushing pushed in at each end so as to keep the wire absolutely out of contact with the conducting pipe.

Automatic Cut-outs such as circuit breakers and fuses should be placed on all service wires as near as possible to the point where they enter the building, on the inside of the walls, and arranged to cut off the entire current from the building.

The cut-out or circuit breaker should always be the first thing that the service wires are connected to after entering the building; the switch next, and then the other fixtures or devices in their order. This arrangement is made so that the cut-out or



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circuit breaker will protect all wiring in the building, and the opening of the switch will disconnect all the wiring.

These automatic cut-outs should not, however, be placed in the immediate vicinity of easily ignitible stuff, nor where exposed to inflammable gases or dust, or to flyings of combustible material, as the arcing produced whenever they break the circuit might cause a fire or explosion. When they are exposed to dampness they should be inclosed in a waterproof box or mounted on porcelain knobs. All cut-outs and circuit breakers should be supported on bases of non-combustible, non-absorptive insulating material. Cut-outs should be provided with covers when not arranged in approved cabinets, so as to obviate any danger of the melted fuse metal coming in contact with any ignitible substance.

Cut-outs should operate successfully under the most severe conditions they are liable to meet with in practice, on short circuits, with fuses rated at 50 per cent above, and with a voltage 25 per cent above, the current and voltage for which they are designed. Circuit breakers should also be designed to operate successfully under the severe conditions liable to be met with in practice, or at 50 per cent above the current and with a voltage of 25 per cent above that for which they are designed. All cut-outs and circuit breakers should be plainly marked, and where it will always be visible, with the name of the maker as well as the current and voltage for which the device is designed.

Cut-outs or circuit breakers should be placed at every point where a change is made in the size of wire, unless such a device in the larger wire will protect the smaller. They should never be placed in canopies or shells of fixtures, but should be so placed that no set of incandescent lamps, whether grouped on one fixture or several fixtures or pendants, requiring a current of more than six amperes, should be dependent upon one cut-out. Special permission may be given in writing by the Inspection Department having jurisdiction, in case extra large or special chandeliers are to be used. Fused rosettes, when used with flexible cord pendants, are considered as equal to a cut-out. Fuses for cut-outs should not have a capacity to exceed the carrying capacity of the wire; and where circuit breakers are used they should not be set more than 50 per cent above the allowable carrying capacity of the wire, unless a fusible cut-out is also installed in the circuit.

Circuit breakers open at exactly the current they are set for, and instantly; therefore it is necessary to get them considerably above the ordinary amount of current required, to keep them from constantly opening on slight fluctuations. When this is the case a double-pole fusible cut-out should be added to protect the wire from a heavy, steady current, which may be maintained just below the opening point of the circuit breaker. The fuse requires a little time to heat, and therefore would not blow out with a momentary rise of current which might open the circuit breaker if set as low as necessary to protect the wire, which may be of a size only large enough for the figured amount of current under ordinary conditions of operation. If, however, in the case of motor wiring, the size of wire is 50 per cent above the figured size for the motor's average current, as it should be, then the introduction of a fusible cut-out in addition to the circuit breaker is unnecessary.

Insulating Joints should be made entirely of material that will resist the action of illuminating gases, and that will not give way or soften under the heat of an ordinary gas flame, or leak under a moderate pressure.

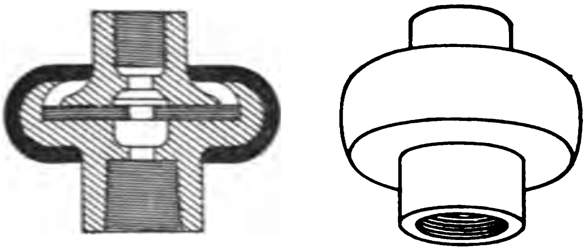

Fig. 12.

The Macallen Insulating Joint.

They should be so arranged that a deposit of moisture will not destroy the insulating effect, and should have an insulation resistance of at least 250,000 ohms between the gas pipe attachments, and be sufficiently strong to resist the strain they will be liable to be subjected to in being installed.

Insulating joints should not contain any soft rubber in their composition. The insulating material should be of some hard and durable material, such as mica. See Fig. 12.

Insulation Resistance. The wiring in any building should test free from grounds, *i. e.,* the complete installation should have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.), of not less than the following:

Up to—

5 amperes	4,000,000
10 amperes	2,000,000
25 amperes	800,000
50 amperes	400,000
100 amperes	200,000
200 amperes	100,000
400 amperes	50,000
800 amperes	25,000
1,600 amperes	12,500

All cut-outs and safety devices in place in the above.

Where lamp sockets, receptacles and electroliers, etc., are connected, one-half of the above will be required.

Knife Switches. Switches should be placed on all service wires, either overhead or underground, in a readily accessible place, as near as possible to the point where the wires enter the building, and arranged to cut off the entire current.

Knife switches should always be installed so that the handle will be up when the circuit is closed, so that gravity will tend to open rather than close the switch. They should never be single-pole except when the circuit which they control is carrying not more than six 16-candle-power lamps or their equivalent.

Double-pole switches are always preferable to single-pole, as they absolutely disconnect the part of the circuit out of use.

Flush Switches. Where gangs of flush switches are used, whether with conduit systems or not, the switches should be enclosed in boxes constructed of, or lined with, fire-resisting material.

Where two or more switches are placed under one plate, the box should have a separate compartment for each switch. No push buttons for bells, gas lighting circuits, or the like, should be placed in the same wall plates with switches controlling electric light or power wiring.

Snap Switches, like knife switches, should always be mounted on non-combustible, non-absorptive, insulating bases, such as slate or porcelain, and should have carrying capacity sufficient to prevent undue heating.

When used for service switches they should indicate at sight whether the current is "on" or "off." Indicating switches should be used for all work, to prevent mistakes and possible accidents. The fact that lights do not burn or the motor does not run is not necessarily a sure sign that the current is off.

Every switch, like every piece of electrical apparatus, should be plainly marked, where it is always visible, with the maker's name and the current and voltage for which it is designed.

On constant-potential systems, these switches, like knife switches, should operate successfully at 50 per cent overload in amperes with 25 per cent excess voltage, under the most severe conditions they are likely to meet with in practice. They should have a firm contact, should make and break readily, and not stop when motion has once been imparted to the handle. When this style of switch is used for constant-current systems, they should close the main circuit and disconnect the branch wires when turned "off;" should be so constructed that they will be automatic in action, not stopping between points when started; and should prevent an arc between the points under all circumstances. They should also indicate at sight whether the current is "on" or "off."

Incandescent Lamps. Table X is compiled from a series of careful tests on a number of incandescent lamps taken from a large stock at random.

Poor regulation of voltage results in more trouble with incandescent lamps and their users than any other fault in electric lighting service.

Some men act on the theory that so long as the life of a lamp is satisfactory, an increase of voltage, either temporary or permanent, will increase the average light. The fact is that when lamps are burned above their normal rating the average candle-power of all the lamps on the circuit is decreased.

Excessive voltage is thus a double error—it decreases the

TABLE X.

Incandescent Lamp Data.

VOLTS.	C. P.	Amp.	Watts Per Lamp.	Watts Per C. P.	Hot Res.
52	10	.67	35	3.50	77.61
"	16	1.08	56	"	48.14
"	20	1.34	70	"	38.80
"	24	1.62	84	"	32.09
"	32	2.15	112	"	24.18
"	50	3.36	175	"	15.47
"	100	6.73	350	"	7.72
"	150	10.09	525	"	5.15
104	10	.34	35	3.50	305.88
"	16	.54	56	"	192.59
"	20	.67	70	"	185.22
"	24	.81	84	"	128.39
"	32	1.08	112	"	96.29
"	50	1.68	175	"	61.90
"	100	3.36	350	"	30.95
"	150	5.05	525	"	20.59
110	10	.32	35	3.50	343.75
"	16	.51	56	"	215.68
"	20	.64	70	"	171.87
"	24	.76	84	"	144.73
"	32	1.02	112	"	107.84
"	50	1.59	175	"	69.18
"	100	3.18	350	"	34.59
"	150	4.77	525	"	23.06
220	16	.291	64	4.00	756.01
"	32	.582	128	"	379.31

otal light of the lamps, and increases the power consumed. If ncreased light is needed, 20-candle-power lamps should be intalled instead of raising the pressure. Their first cost is the ame as 16-candle-power lamps; they take but little more current han 16-candle-power lamps operated at high voltage and give reater average light.

Increased pressure also decreases the commercial life of the mp, and this decrease is at a far more rapid rate than the crease of pressure, as shown in the following table. This table shows the decrease in life of standard 3.1-watt lamps due to increase of normal voltage.

Per Cent of Normal Voltage	Life Factor
100	1.000
101	.818
102	.661
103	.562
104	.452
105	.374
106	.310

From this table it is seen that 3 per cent increase of voltage halves the life of a lamp, while 6 per cent increase reduces the life by two thirds.

Intensity or Brilliancy. The average brilliancy of illumination required will depend on the use to which the light is put. A dim light that would be very satisfactory for a church would be wholly inadequate for a library and equally unsuitable for a ballroom.

The illumination given by one candle at a distance of one foot is called the "candle-foot" and is taken as a unit of intensity. In general, intensity of illumination should nowhere be less than one candle-foot, and the demand for light at the present time quite frequently raises the brilliancy to double this amount. As the intensity of light varies inversely with the square of the distance, a 16-candle-power lamp gives a candle-foot of light at a distance of four feet. A candle-foot of light is a good intensity for reading purposes.

Assuming a 16-candle-power lamp as the standard, it is generally found that two 16-candle-power lamps per 100 square feet of floor space give good illumination, three very bright and four brilliant. These general figures will be modified by the height of ceiling, color of walls and ceiling, and other local conditions. The lighting effect is reduced, of course, by an increased height of ceiling. A room with dark walls requires nearly three times as many lights for the same illumination as a room with walls painted white. With the amount of intense light available in arc and incandescent lighting, there is danger of exceeding "the limits of effective illumination" and producing a "glaring intensity" which should be avoided as carefully as too little intensity of illumination.

Distribution concerns the arrangement of the various sources of light and the determination of their candle-power. The object should be to "secure a uniform brilliancy on a certain plane, or within a given space. A room uniformly lighted, even though comparatively dim, gives an effect of much better illumination than where there is great brilliancy at some points and comparative darkness at others. The darker parts, even though actually light enough, appear dark by contrast, while the lighter parts are dazzling. For this reason naked lights of any kind are to be avoided, since they must appear as dazzling points in contrast with the general illumination."

The Arrangement of the Lamps is dependent very largely upon existing conditions. In factories and shops, lamps should be placed over each machine or bench so as to give the necessary light for each workman. In the lighting of halls, public buildings and large rooms, excellent effects are obtained by dividing the ceilings into squares and placing a lamp in the center of each square. The size of square depends on the height of ceiling and on the intensity of illumination desired. Another excellent method consists in placing the lamps in a border along the walls near the ceiling.

For the illumination of show windows and for display effects, care must be taken to illuminate by reflected light. The lamps should be so placed as to throw their rays upon the display without casting any direct rays on the observer.

The relative value of high candle-power lamps in comparison with an equivalent number of 16-candle-power lamps is worthy of notice. Large lamps can be efficiently used for lighting large areas, but in general a given area will be much less effectively lighted by high candle-power lamps than by an equivalent number of 16-candle-power lamps. For example, sixteen 64-candle-power lamps distributed over a large area will not give as good general illumination as sixty-four 16-candle-power lamps distributed over the same area. High candle-power lamps are useful chiefly when a brilliant light is needed at one point, or where space is limited and an increase in illuminating effect is desired.

The Relative Value of the Arc and Incandescent Systems of Lighting is frequently difficult to determine. Incandescent

TABLE XI.

Tinned Fuse Wire.

[illegible]

[illegible]	[illegible]	Diameter in Mils.	Feet Per Pound.
[illegible]	[illegible]	10	[illegible]
[illegible]	[illegible]	17	960
1	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	510
2	[illegible]	25	430
3	[illegible]	[illegible]	370
4	[illegible]	30	300
5	2	35	212
6	2	[illegible]	[illegible]
7	2	44	[illegible]
8	2	[illegible]	130
9	2	54	98
10	2	58	80
[illegible]	3	[illegible]	70
[illegible]	3	68	60
[illegible]	3	[illegible]	52
[illegible]	3	[illegible]	49
[illegible]	3	[illegible]	43
[illegible]	4	86	38
[illegible]	4	[illegible]	32
[illegible]	4	[illegible]	26
[illegible]	4	[illegible]	22
[illegible]	4	122	18
45	4	[illegible]	17
50	4	147	12.5
60	5	160	10.3
70	5	172	9.0
75	5	178	8.3
80	5	190	7.5
90	5	198	6.7
100	5	220	5.5

lamps have the advantage that they can be distributed so as to avoid the shadows necessarily cast by one single source of light. Arc lamps used indoors with ground or opal globes cutting off half the light, have an efficiency not greater than two or three times that of an incandescent lamp. Nine 50-watt, 16-candle-power lamps consume the same power as one full 450-watt arc lamp. It has been found that unless an area is so large as to require 200 or 300 incandescent lights distributed over it, arc lamps requiring equal total power will not light the area with so uniform a brilliancy.

Fuses should have contact surfaces or tips of harder metal, having perfect electrical connection with the fusible part of the strip.

The use of the hard metal tip is to afford a strong mechanical bearing for the screws, clamps or other devices provided for holding the fuse.

Fuses should be stamped with about 80 per cent of the maximum current they can carry indefinitely, thus allowing about 25 per cent overload before the fuse melts.

With naked open fuses of ordinary shapes and not over 500 amperes capacity, the maximum current which will melt them in about five minutes may be safely taken as the melting point, as the fuse practically reaches its maximum temperature in this time. With larger fuses a longer time is necessary.

The following table shows the minimum break distance, and the separation of the nearest metal parts of opposite polarity, for open-link fuses when mounted on slate or marble bases, for different voltages and different currents:

	Separation of nearest metal parts of opposite polarity.	Minimum break distance.
125 VOLTS OR LESS.		
10 amperes or less	¾ inch	¾ inch
11—100 amperes	1 inch	¾ inch
101—300 amperes	1 inch	1 inch
125 TO 250 VOLTS.		
10 amperes or less	1½ inch	1¼ inch
11—100 amperes	1¾ inch	1¼ inch
101—300 amperes	2 inch	1½ inch

Fuse Terminals should be stamped with the maker's name or initials, or some known trade-mark.

Fuse Wire. Table XI shows the sizes of fuse wire and the approximate current-carrying capacity of each size.

Fuses have been known to blow out simply from the heat due to poor contact when nowhere near their current-carrying capacity had been reached. They should be so put up and protected that nothing will tend to rupture them except an excessive flow of current. No fuse of the larger sizes ever blew out without causing a greater or less fire risk.

Fuses blow out or melt from excessive heat, and nothing else, and are therefore not as instantaneous in their action as a circuit breaker, which is constantly cared for and kept clean. Central stations or large isolated plants subject to greatly varying loads should have their lines and generators protected by both fuses and magnetic circuit breakers as a double protection against excessive current.

The lengths of fuses and distances between terminals are important points to be considered in the proper installation of these electrical "safety valves." No fuse block should have its terminal screws nearer together than one inch on 50 or 100-volt circuits, and one inch additional space should always be allowed between terminals for every 100 volts in excess of this allowance. For example, 200-volt circuits should have their fuse terminals 2 inches apart, 300-volt 3 inches, and 500-volt 5 inches. This rule will prevent the burning of the terminals on all occasions of rupture from maximum current, and this maximum current means a "short circuit." Good contact is absolutely essential in the installation and maintenance of fuses. See that the copper tips to all fuses are well soldered to the fuse wire, and furthermore see that the binding screw or nut is firmly set up against this copper tip when the fuse is placed in circuit; a 100-ampere fuse can be readily "blown" by 25 amperes if the above precautions are not carried out. Poor contact in every case can cause a heating beyond the carrying capacity of the largest fuses. On the other hand, much damage can be done by using too short fuses and too large terminals, as the radiation of heat from the short piece of fuse wire to the heavy metal terminals and set screws or nuts can very easily raise the current-carrying capacity of a fuse designed to carry 50 amperes to 100 amperes, or even more. All open-link fuses should be placed in cut-out cabinets when possible.

Cut-out Cabinets should be so constructed, and cut-outs so arranged, as to obviate any danger of the melted fuse metal coming in contact with any substance which might be ignited thereby.

A suitable box may be made of marble, slate or wood, strongly put together, the door to close against a rabbet so as to be perfectly dust tight, and it should be hung on strong hinges and held closed by a strong hook or catch. If the box is wood the inside should be lined with sheets of asbestos board about one-sixteenth of an inch in thickness, neatly put on and firmly secured in place by shellac and tacks. The wires should enter through holes bushed with porcelain bushings, the bushings tightly fitting the holes in the box, and the wires tightly fitting the bushings (using tape to bind up the wire, if necessary), so as to keep out the dust.

The Enclosed Fuse, or "Cartridge Fuse" (see Fig. 13), consists of a fusible strip or wire placed inside of a tubular holding jacket filled with porous or powdered insulating material through which the fuse wire is suspended from end to end and which surrounds the fuse wire. The wire, tube and filling are made into one complete, self-contained device with brass or copper terminals or ferrules at each end, the fuse wire being soldered to the inside of the ferrules. When an inclosed fuse "blows" by excess current or short circuit the gases resulting are taken up by the filling, the explosive tendency is reduced and flashing and arcing are eliminated.

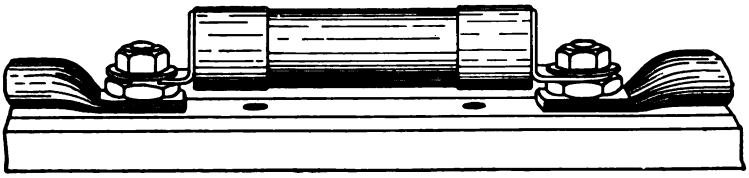

Fig. 13.
Enclosed Fuse.

Incandescent Lamps in Series Circuits should be wired with

TABLE XII.

Dimensions of Enclosed Fuses.

By Joseph Sachs.

VOLTS	Class, Amps.	Tube Length, Inches.	Tube Diam., Inches.	Fuse Length, Inches.	VOLTS	Class, Amps.	Tube Length, Inches.	Tube Diam., Inches.	Fuse Length, Inches.	VOLTS	Class, Amps.	Tube Length, Inches.	Tube Diam., Inches.	Fuse Length, Inches.
220	1-8	2 3/16	3/8	1	500	1-10	4 5/8	3/8	3	2,500	1-12	5 1/4	1/2	4 1/2
	10-15	2 11/16	3/8	1		12-25	5 1/4	1/2	3 1/4		15-30	5 1/4	5/8	4 5/8
	20-30	3 3/16	1/2	1 1/4		30-50	5 3/4	3/4	3 1/2		35-50	6 1/4	7/8	5
	35-50	3 1/4	3/4	1 1/2		60-100	6 1/4	1	3 1/2		60-75	6 11/16	1 1/8	5 5/8
	60-100	4 1/8	7/8	1 1/2		125-150	6 1/4	1 1/4	3 5/8		80-100	6 11/16	1 1/4	5 5/8
	125-150	4 1/8	1	1 3/4		175-225	6 7/16	1 1/2	3 3/4					
	175-225	4 11/16	1 1/4	2 1/2		250-400	6 5/8	2	3 7/8					
	250-400	4 13/16	1 1/2	2 1/2		500-600	10	2 1/2	4					
	500-600	6 3/16	2	2 1/2										
5,000	1/2-12	15 1/8	3/4	13	10,000	1/2-12	24	3/4	18	20,000	1/4-10	30	1	24
	15-30	15 1/8	1	13		15-30	24	1	18					
	35-50	18 1/8	1 1/8	14										

the same precaution as for series arc lighting and each lamp should be provided with an automatic cut-off.

Each lamp should be suspended from an approved hanger board by means of a rigid tube, to prevent the wires from constant swinging.

No electro-magnetic device for switches and no system of multiple, series, or series-multiple lighting in this class of work should be used. Under no circumstances should incandescent lamps in series circuits be attached to gas fixtures, as the high voltage necessarily employed in this class of lighting should be kept as far as possible from gas piping, which is so thoroughly grounded or likely to be.

When incandescent lamps are used for decorative purposes, as in the use of miniature colored lamps, and it is necessary to run two or more in series, permission should always be secured, in writing, from the Inspection Department having jurisdiction.

Arc Lamps should be carefully isolated from inflammable material, should be provided at all times with a glass globe surrounding the arc and securely fastened upon a closed base. No broken or cracked globes should be used, as they are designed to prevent hot bits of carbon from falling to the floor should they fall from the carbon holder. All globes for inside work should be covered with a wire netting having a mesh not exceeding one and one-quarter inches, to retain the pieces of the globe in position should the latter become broken from any cause. A globe thus broken should be replaced at once. When arc lamps are used in rooms containing readily inflammable material they should be provided with approved spark arresters, which should be made to fit so closely to the upper orifice of the globe that it would be impossible for any sparks thrown off by the carbons to escape. It is safer to use plain carbons and not copper-plated ones in such rooms, or better still, an enclosed arc lamp, one having its carbons enclosed in a practically tight glass globe which is inside the outer globe. Where hanger-boards are not used arc lamps should be hung from insulating supports other than their conductors.

All arc lamps should be provided with reliable stops to prevent carbons from falling out in case the clamps become loose.

and all exposed parts should be carefully insulated from the circuit. Each lamp for constant-current systems should be provided with an approved hand switch, and also an automatic switch that will shunt the current around the carbons, so that the lamp will thus cut itself out of circuit should the carbons fail to feed properly. If the hand switch is placed anywhere except on the lamp itself, it should comply in every respect with the requirements for switches on hanger-boards as described under the latter heading.

Arc Light Wiring. All wiring for high-potential arc lighting circuits should be done with "Rubber-Covered" wire. The wires should be arranged to enter and leave the building through an approved double-contact service switch, which should close the main circuit and disconnect the wires in the building when turned "off." These switches should be so constructed that they will be automatic in their action, not stopping between points when started, and preventing arcing between points under any circumstances, and should indicate plainly whether the current is "on" or "off." Never use snap switches for arc lighting circuits. All arc light wiring of this class should be in plain sight and never enclosed except when required, and should be supported on porcelain or glass insulators which separate the wires at least one inch from the surface wired over. The wires should be kept rigidly at least eight inches apart, except of course within the lamp, hanger-board, or cut-out box or switch. On side walls the wiring should be protected from mechanical injury by a substantial boxing retaining an air space of one inch around the conductors, closed at the top (the wires passing through bushed holes), and extending not less than seven feet above the floor. When crossing floor timbers in cellars or in rooms, where they might be exposed to injury, wires should be attached by their insulating supports to the under side of a wooden strip not less than one-half an inch in thickness.

Arc Lamps on Low-Potential Circuits should have a cut-out for each lamp or series of lamps. The branch conductors for such lamps should have a carrying capacity about 50 per cent in excess of the normal current required by the lamp or lamps, to provide for the extra current necessary when the lamps are started, or, should a carbon become stuck, to prevent over-fusing the wires. If any resistance coils are necessary for adjustment or regulation, they should be enclosed in non-combustible material and be treated as sources of heat; it is preferable that such resistance coils be placed within the metal framework of the lamp itself. Incandescent lamps should never be used for resistance devices. These lamps should be provided with globes and spark arresters, as in the case of arc lamps on high-potential series circuits, except when the enclosed arc lamps are used.

Economy Coils, or compensator coils, for arc lamps should be mounted on glass or porcelain, allowing an air space of at least one inch between frame and support, and in general should be treated like sources of heat.

Hanger-Boards should be so constructed that all wires and current-carrying devices thereon will be exposed to view and thoroughly insulated on non-combustible, non-absorptive insulating substance, such as porcelain.

All switches attached to the hanger-board should be so constructed that they will be automatic in their action, cutting off both poles to the lamp, not stopping between points when started, and preventing an arc between points under all circumstances.

Electric Heaters should always be treated as sources of heat and kept away from inflammable materials. Each heater should have a cut-out and indicating switch, and all attachments from the feed wires to the heater should be kept in plain sight, easily accessible and protected from interference. Each heater should have a name-plate giving the maker's name and the normal capacity in volts and amperes.

Approved Apparatus and Supplies. Every article or fitting intended for use in electrical wiring or construction or in connection therewith should, before being manufactured or placed upon the market, be examined and approved by the Underwriters' National Electric Association for use under the rules and requirements of the National Board of Fire Underwriters and placed upon their official list of "approved" electrical fittings.

Any new article, therefore, or modification of an old article, intended to be placed in general electrical use, should first be sent for examination and test to the laboratory of the Electrical Bureau of the National Board of Fire Underwriters, 67 East Twenty-first street, Chicago, Ill.

If the article is approved it will be placed upon the list of fittings, which list is revised quarterly. When buying electrical supplies of any description make sure that they have been approved. If there is any question about it, make your supply dealer give you a guarantee that they will be approved by the Fire Underwriters' Inspector if installed in accordance with the rules and requirements of the National Board of Underwriters.

Electrical Inspection. The principal points regarding the safe installation of dynamos, motors, outside and inside wiring, as required by the insurance underwriters, have been set forth in this paper. There will probably arise questions which cannot be settled by reference to the suggestions herein contained, and therefore a great deal has to be left to the judgment of the constructing engineer and inspector. In every such case the Inspection Department having jurisdiction should be consulted with perfect assurance that nothing unreasonable will ever be demanded in the way of special construction.

Every piece of wiring or electrical construction work, whether open or concealed, should be and usually is inspected, and notice, therefore, should always be sent by the contractor or engineer to the board having jurisdiction, immediately upon completion of any work.

Negligence in this matter has frequently caused floors to be torn up when doubtful work has been suspected, and at the cost of the parties who installed the wiring.

The insurance inspector cannot order any piece of wiring taken out or altered, but always reports whether or not the plant is installed in a manner which will reduce the fire risk to a minimum. If the inspector has occasion to recommend any changes which he considers for the safety of the building, and such changes are not immediately made, he recommends that the insurance rate on the building be so raised that it will, in the end, be found advisable to attend to his suggestions, which are in every case reasonable.

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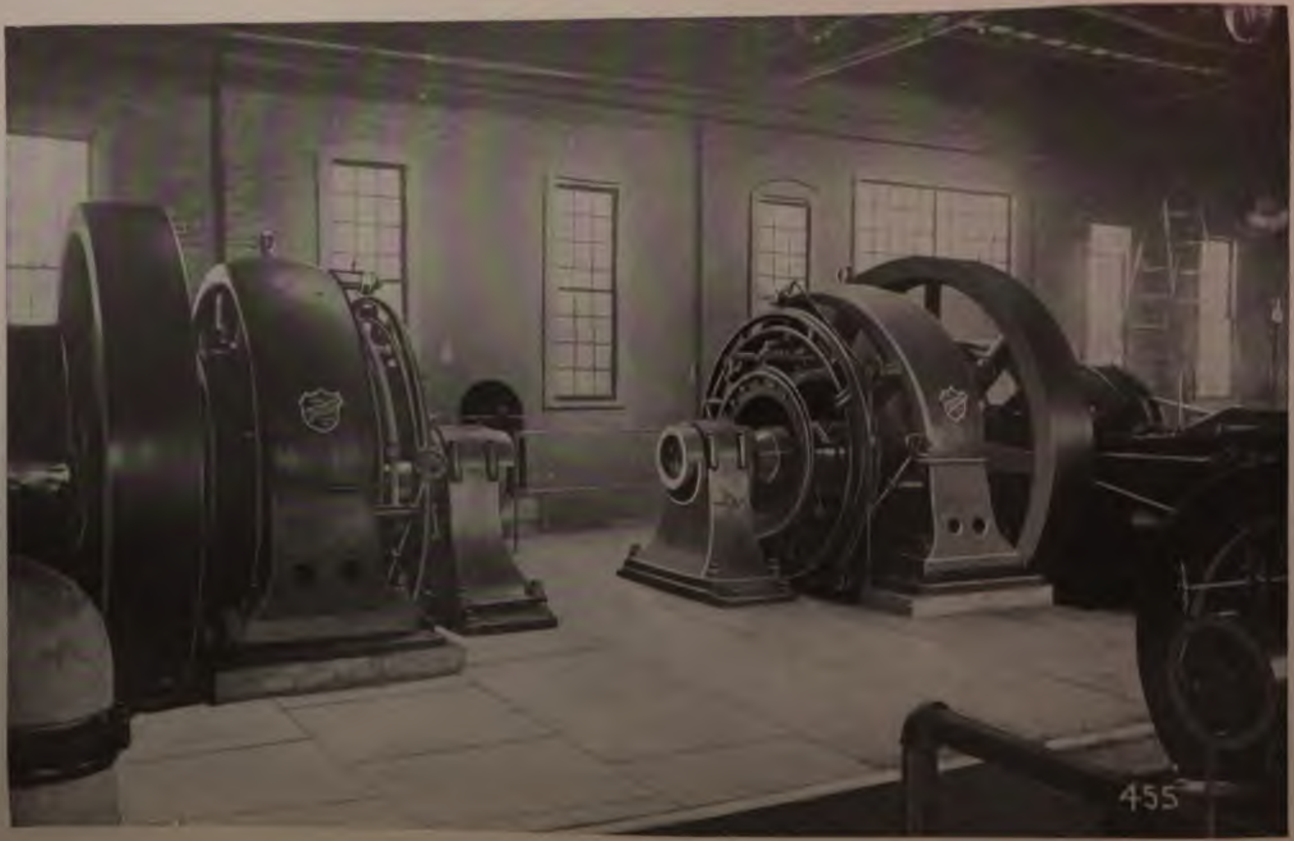

ENGINE-TYPE GENERATORS

ELECTRIC BELL WIRING.

In wiring for electric bells to be operated by batteries, the danger of causing fires from short circuits or poor contacts does not exist as in the case of wiring for light and power, because the current strength is so small. Neither is the bell-fitter responsible to city inspectors or fire underwriters. On this account, bell fitting is too often done in a careless and slovenly manner, causing the apparatus to give unsatisfactory results and to require frequent repairs, so that the expense and inconvenience in the end far more than offset any time saved by doing an inferior grade of work. Hence, at the outset it is well to state that as much care should be taken in the matter of joints and insulation of bell wiring as in wiring for light or power.

If properly installed, the electric bell forms a reliable and yet inexpensive means of signaling, and is far superior to any other. On this account practically every new building is fitted throughout with electric bells.

In addition to the necessity of thoroughness already mentioned, care should be taken to use only reliable apparatus which must be installed in accordance with the fundamental principles on which its satisfactory operation depends.

WIRE.

The common sizes of wire in use for bell work are Nos. 18, 20, and 22. In general, however, No. 20 will be found satisfactory as it is usually sufficiently large, while in many cases No. 22 is not strong enough from a mechanical standpoint.

It is important that the wires should be well insulated to prevent accidental contacts with the staples or other wires. First of all the wire should be tinned, as this prevents the copper from being acted upon by the sulphur in the insulation. It also facilitates soldering. The inner coating of insulation should be of

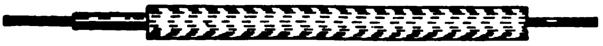

Fig. 1.

india rubber, surrounded by several longitudinal strands of cotton, outside of which are wound several strands of colored cotton laid on spirally. This is next immersed in melted paraffin wax and polished by friction. A short length of approved electric bell wire is shown in Fig. 1.

When ordering wire, it is well to have it furnished in several different colors as this greatly facilitates both the original installation and later repairs, because in this way one line may be distinguished from another, taps from main lines, etc. Moreover, a faulty wire having been found, it is possible to identify it at any desired section of its length.

METHODS OF WIRING.

In running wires, the shortest and most direct route should, of course, be taken between the battery, bells, and bell pushes. There are two cases to be considered. The better method is that in which the wires are run before the building is completed, and the wiring should be done as soon as the roof is on and the walls are up. In this case the wires are usually run in zinc tubes secured to the walls with nails. The tubes should be from ⅜ inch to ½ inch in diameter, preferably the latter. It is better to place the wires and tubes simultaneously, but the tubes may be put in place first and the wires drawn in afterward, although this latter plan has the objection that the insulation is liable to become abraded when the wires are drawn in. In joining up two lengths of tube, the end of one piece should be opened up with the pliers so that it may receive the end of the other tube, which should also be opened up, but to a less extent, to prevent wear upon the insulation. Specially prepared paper tubes are sometimes substituted for the zinc.

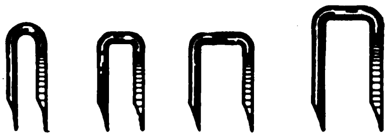

Fig. 2.

If the building is completed before the wiring is done, the concealed method described above cannot be used, and it is necessary to run the wires along the walls supported by staples, where they will be least conspicuous. Fig. 2 shows ordinary double-pointed tacks, Fig. 3 shows an insulating saddle staple which is to be recommended. Two wires should never be secured under the same staple if it can possibly be avoided, owing to the danger of short circuits. With a little care it is usually possible to conceal the wiring behind the picture moulding, along the skirting-board, and beside the door posts, but where it is impossible to conceal it, a light ornamental casing to match the finish of the room, may be used. It is sometimes advisable to use twin wires or two insulated wires run in the same outer covering.

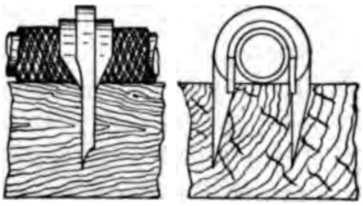
Fig. 3.

In some cases it is well to run the wires under the floors, laying them in notches in the tops of the joists or in holes bored about two inches below the tops of the joists.

JOINTS.

When making a joint, care should be taken to have a firm, clean connection, both mechanically and electrically, and this must always be soldered to prevent corrosion. The insulation should be stripped off the ends of the wires to be joined, for a distance of about 2 inches, and the wires made bright by scraping or sandpapering. They should then be twisted tightly and evenly together as shown in Fig. 4.

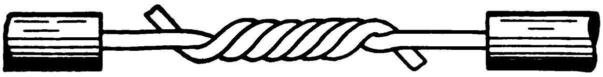
Fig. 4.

Next comes the operation of **soldering**, which is absolutely necessary if a permanent joint from an electrical standpoint is to be obtained. A joint made without solder may be electrically sound at first, but its resistance rapidly increases, due to deterioration of the joint. As has already been stated, the wires should be made bright and clean before they are twisted together. Soldering fluids should never be used, because they cause corrosion of the wire. The best flux to use is resin or composite candle. The soldering should always be done with a copper bit rather than with a blowpipe or wireman's torch.

A convenient form of soldering tool consists of a small copper bit having a semicircular notch near the end. This bit should, of course, be well tinned. It is then heated over a spirit lamp, or wireman's torch, and the notch filled with soft solder. Lay the joint, which has previously been treated with the flux, in this notch and turn it so that the solder runs completely around among the spirals of the joint. The loose solder should be shaken off or removed with a bit of rag. When the joint is set, it should be insulated with rubber tape, so that it will be protected as perfectly the other portions.

It is often possible to save a considerable length of wire and amount of labor by using a ound return, which, if properly arranged, will give very satisf y results, although a complete metallic circuit is always to eferred. Where water or gas mains are available, a good ground may be obtained by connecting to them, being sure to have a good connection. This may be secured by scraping a portion of the pipe perfectly bright and clean and then winding this with bare wire; the whole is then well soldered. An end should be left to which the wire from the bell circuit is twisted and soldered. If such mains are not available, a good ground can be obtained by connecting the wire from the bell circuit, as described above, to a pump pipe. In the absence of water and gas mains, and of a pump pipe, a ground may be obtained by burying beneath permanent moisture level a sheet of copper or lead, having at least five square feet of surface, to which the return wire is connected. The ground plate should be covered with coke nearly to the surface; the hole should then be filled in with ordinary soil well rammed.

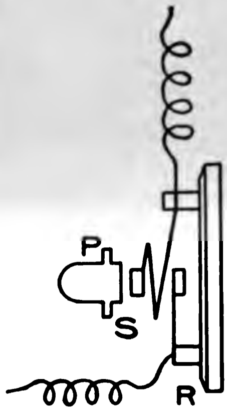

Fig. 5.

OUTFIT.

The three essential parts of the electric bell outfit are the bell push, which furnishes a means of opening and closing the circuit at will, the battery, which furnishes the current for operating the bell, and the bell itself. Before discussing the combination of these pieces of apparatus in the complete circuit, let us take up the individual parts in order.

A bell push is shown diagrammatically in Fig. 5. In this illustration P is the push button; when this is pressed upon it brings the point of the spring S in contact with the metal strip R, thus closing the circuit with which it is connected in series. Normally the springs are separated as shown, and the circuit is accordingly open.

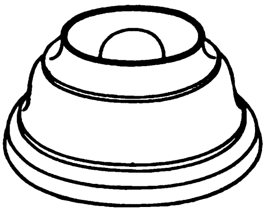

Fig. 6.

Bell pushes are made in various designs and styles, from the simple wooden push shown in Fig. 6 to very elaborate and expensive articles. Fig. 7 shows four cast bronze pushes of neat appearance and moderate price.

Batteries. Electric bells are nearly always operated on the open circuit plan, and hence the battery used is generally of the open circuit type, such as the Leclanche cell, which is used very largely except for heavy work. This is a zinc-carbon cell in which the excitant is sal-ammoniac dissolved in water. Polarization is prevented by peroxide of manganese, which gives up part of its oxygen, combining with the hydrogen set free and forming water.

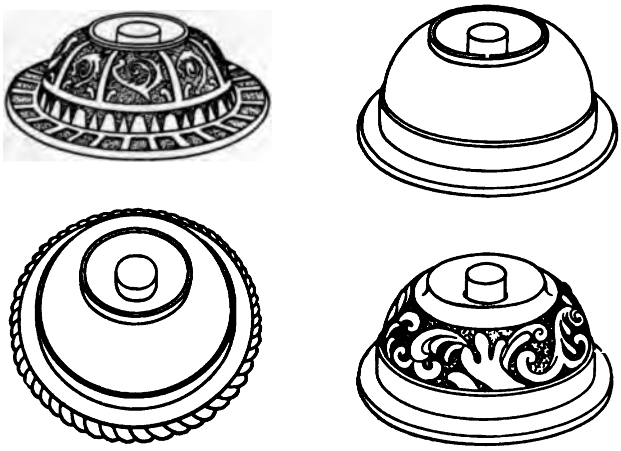

Fig. 7.

atteries are also frequently used for bell work, their prin dvantage being cleanliness, as they cannot spill. Dry cells eally a modification of the Leclanche type, as they use zinc and arbon plates and sal-ammoniac as the exciting agent. rnley cell, which is one of the principal types of dry cell, ha an ctrolyte composed of sal-ammoniac, chloride of zinc, ir, and water. This compound when mixed is a semi- s which quickly stiffens after being poured into the cup. depolarizing agent is peroxide of manganese, the same as is in the Le cell, ng packed around the carbon cyl . The top of the cell is sealed with umen or some similar substance. very heavy work the Edison-Lalande and the Fuller types of cell are best suited, while for closed circuit work the gravity cell is most satisfactory.

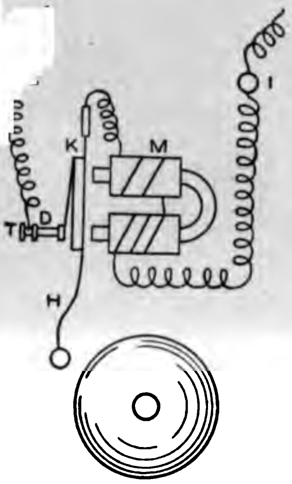

Fig. 8.

Bell. It is a well-known fact that if a current of electricity flows through a coil of wire wound on an iron core, the core becomes magnetized and is capable of attracting any magnetic substances to itself. The operation of the electric bell, like that of so many other pieces of electrical apparatus, depends upon this fact. A diagrammatic representation of an electric bell is shown in Fig. 8, in which M is an electromagnet composed of soft-iron cores on which are wound coils of insulated wire. The armature is mounted upon a spring K, and carries a hammer H at its end for striking the gong. On the back of the armature is a spring which makes contact at D with the back stop T. The action of the bell is as follows: When the circuit is closed through the bell a current flows from terminal 1, around the coils of the magnet, through the spring K and contact point D, through the back stop T, to terminal 2. In flowing around the electromagnet the current magnetizes its core, which consequently attracts the armature. This causes the hammer H to strike the gong. While in this position the contact at D is broken, the current ceases to flow around the electromagnet and the cores consequently lose their attractive force. The armature is then carried back to its original position by the spring K, making contact at D, and the process is repeated. The hammer will thus vibrate and the bell continue to ring as long as the circuit is closed.

The type of bell described above is the one most commonly used. Such bells are made in a great variety of shapes and styles, the prices varying accordingly. It is important that platinum tips be furnished at the contact point D, Fig. 8, to prevent corrosion. The bells on the market today are of two classes, the iron box bell and the wooden box bell. A bell of the wooden box type is shown in Fig. 9, and a higher grade bell of the iron frame skeleton type is shown in Fig. 10. Bells without covers should never be used, as dust will settle on the contacts and interfere with their action.

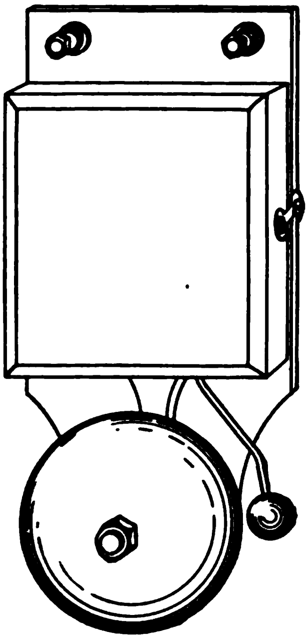

Fig. 9.

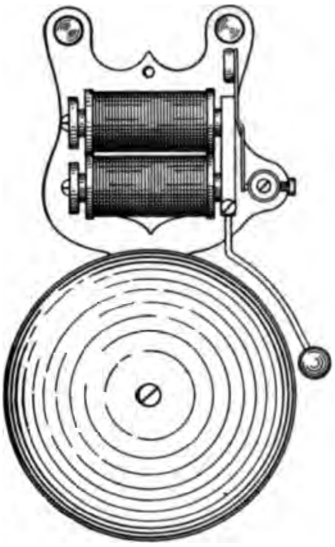

Fig. 10.

CIRCUITS.

The possible combinations of the various parts into complete circuits are so varied that it would be impossible to describe them t, almost every one is to a certain extent a special pr m. It is, however, possible to give typical circuits the underl principles of which can be applied successfully to any particular case.

Fig. 11 shows a bell circuit in its simplest form, in which P presents the push, B the bell, and C the battery; all connected in series. The circuit is normally open at P, and hence no current flows to exhaust the batteries. When P is pressed, the circuit, otherwise complete, is closed and rent passes through the bell sing it to ring, as already ex ned. For instance, the push ht be located beside the front r, the bell in the kitchen and the battery in the cellar; the loca n depending on the results desired and conditions to be met. wire between P and C may, if necessary, be dispensed with and connection made to ground at G and G, as shown by the dotted lines.

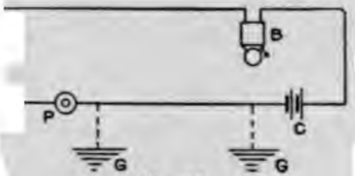

Fig. 11.

Fig. 12 shows an arrangement by means of which one bell B may be controlled by either of the pushes P or P'. This system may be extended to any number of pushes similarly connected.

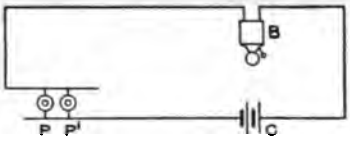

Fig. 12.

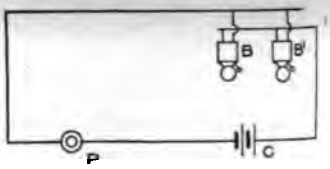

Fig. 13.

A method for ringing two bells simultaneously from one push is shown in Fig. 13, where both bells B and B' will ring from push P. Bells, if connected in this manner, should have as nearly as possible the same resistance, otherwise the bell of lower resistance will take so much current that there will not be a sufficient amount left for the other. Also, the batteries must be of greater current capacity as the amount of current taken is, of course, doubled. This system can be extended to any number of bells connected in this way, up to the limit of capacity of the battery to ring them. Figs.

12 and 13 may be combined so that two or more bells may be rung from any one of two or more pushes.

In Fig. 14 is shown a scheme for ringing either bell, B or B′, from one push and one battery by means of the two-point switch S. When the arm of the switch is on contact 1, the push will ring bell B, and when on contact 2 it will ring bell B′.

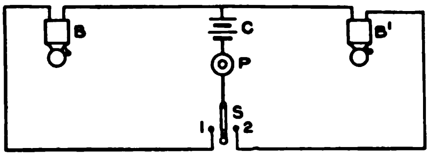

Fig. 14.

In Fig. 15 is shown a method of connecting bells in series so that B and B′ may be rung from P. If all the bells so connected were of the vibrating type, they would not work satisfactorily, as it would be impossible to time them so that the vibrations would keep step, hence only one bell should be of the vibrating type, and the others should have the circuit breakers short-circuited, the vibrating bell serving as interrupter for the whole series. Obviously this system requires a higher voltage than parallel connection, and the cells must be of sufficient E.M.F. to ring the bells satisfactorily. Several bells may be connected in this way, if desired, up to the limit of voltage of the battery.

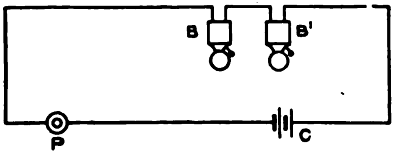

Fig. 15.

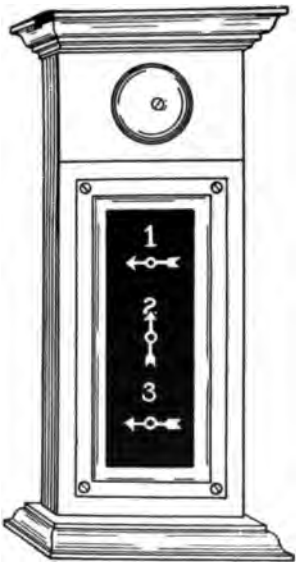

Fig. 16.

Oftentimes a bell is to be rung from several different places. For instance, the bell in an elevator may be rung from any one of rs, or the bell in the office of a hotel may be rung from an o several different rooms. In this case it is necessary to have i device to indicate from which push the bell was rung. annu ciator furnishes this information very well. A three-station annunciator is shown in Fig. 16. The connections for an nnunc r are shown in Fig. 17 where A represents the annun-ciator, B he bell, C the battery, and P^1, P^2, and P^3 the pushes. For in e, when P^1 is pressed, the current passes through the ectro net controlling point 1 on the annunciator which causes

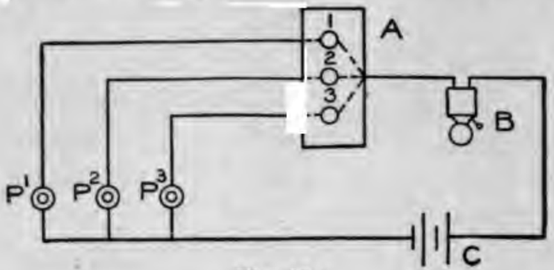

Fig. 17.

the arrow to be turned and at the same time the bell rings. After the attendant has noted the signal, the arrow is restored to its normal position by pressing a lever on the bottom of the annunciator box.

The electric burglar alarm furnishes a very efficient protection and is an application of the principles already described. The circuit, instead of being completed by a push, is completed by contacts placed on the doors or windows so that the opening of either will cause the bell to ring. The same device may be used on money-drawers, safes, etc.

In the case of the electric fire alarm, the signal may be given either automatically when the temperature reaches a certain degree, or pushes may be placed in convenient locations to be operated manually. The pushes should be protected by glass so that they will not be tampered with, it being necessary to break the glass to give the alarm.

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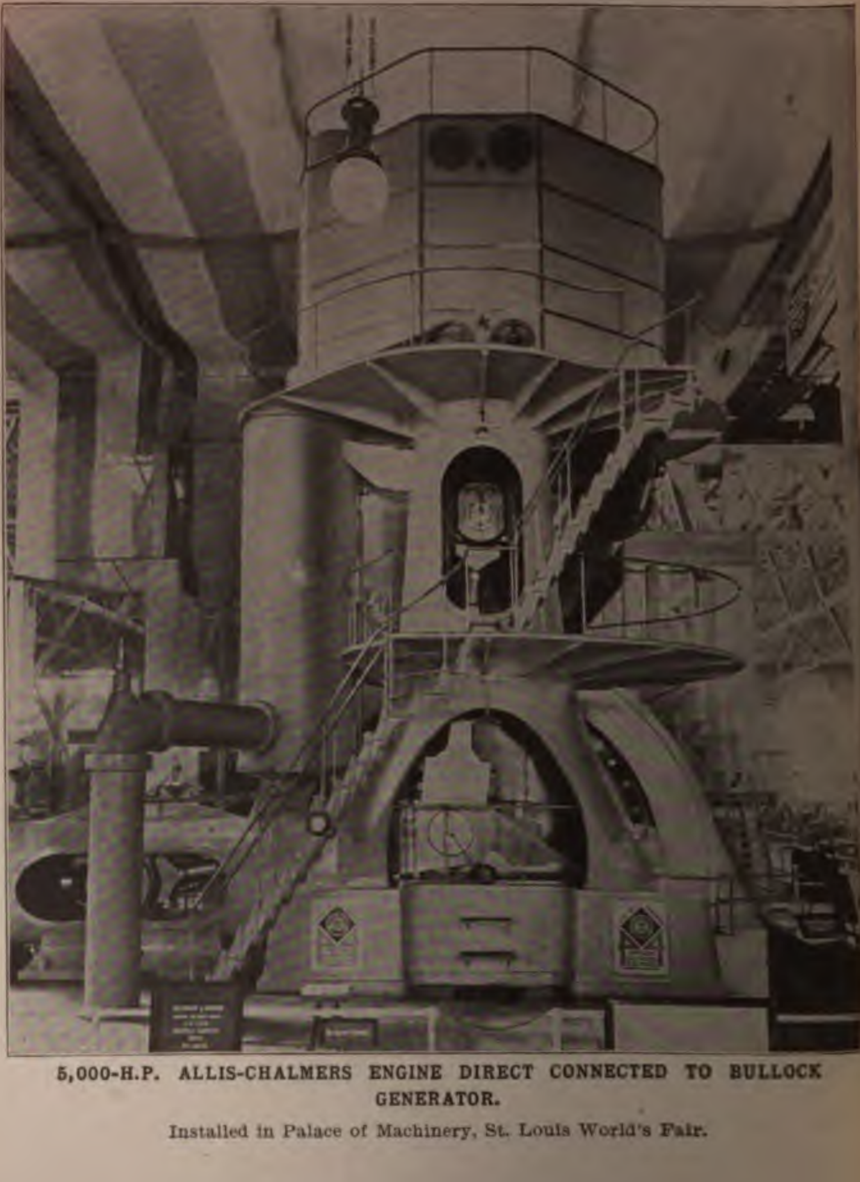

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Installed in Palace of Machinery, St. Louis World's Fair.

ELECTRIC LIGHTING.

HISTORY AND DEVELOPMENT.

The history of electric lighting as a commercial proposition begins with the invention of the Gramme dynamo (by Z. J. Gramme) in 1870, together with the introduction of the Jablochkoff candle or light, which was first announced to the public in 1876, and which formed a feature of the International Exposition at Paris in 1878. Up to this time, the electric light was known to but few investigators, one of the earliest being Sir Humphrey Davy who, in 1810, produced the first arc of any great magnitude. It was then called the "voltaic arc", and resulted from the use of two wood charcoal pencils as electrodes and a powerful battery of voltaic cells as a source of current.

From 1840 to 1859, many patents were taken out on arc lamps, most of them operated by clockwork, but these were not successful, due chiefly to the lack of a suitable source of current, since all depended on primary cells for their power. The interest in this form of light died down about 1859, and nothing further was attempted until the advent of the Gramme dynamo.

The incandescent lamp was but a piece of laboratory apparatus up to 1878, at which time Edison produced a lamp using a platinum spiral in a vacuum, as a source of light, the platinum being rendered incandescent by the passage of an electric current through it. The first successful carbon filament was made in 1879, this filament being formed from strips of bamboo. The names of Edison and Swan are intimately connected with these early experiments.

From this time on, the development of electric lighting has been very rapid, and the consumption of incandescent lamps alone has reached several millions each year. When we compare the small amount of lighting done by means of electricity twenty-five years ago with the enormous extent of lighting systems and the numerous applications of electric illumination as they are today, the growth and development of the art is seen to be very great, and the value of a study of this subject may be readily appreciated. While in many cases electricity is not the cheapest source of power for illumination, its admirable qualities and convenience of operation make it by far the most desirable.

Classification. The subject of Electric Lighting may be classified as follows:

1. The type of lamps used.
2. The methods of distributing power to the lamps.
3. The use made of the light, or its application.
4. Photometry and lamp testing.

Taking up these branches in the order named, we may further subdivide the types of lamps used into:

1. Incandescent lamps.
2. Arc lamps.
3. Special lamps, or lamps which do not require carbon, such as the Nernst lamp, Cooper-Hewitt lamp, etc.

The Incandescent Lamp. The incandescent lamp is by far the most common type of lamp used, and the principle of its operation is as follows:

If a current I is sent through a conductor whose resistance is R, for a time t, the conductor is heated, and the amount of heat generated is:

Heat generated = $I^2R\,t$, $I^2R\,t$ representing joules or watt-seconds.

If the current, material, and conditions are so chosen that the substance may be heated in this way until it gives out light, becomes incandescent, and does not deteriorate too rapidly, we have an incandescent lamp. Carbon is the substance chosen for this conductor and for ordinary lamps it is formed into a small thread or filament. Carbon is selected for two reasons:

1. The material must be capable of standing a very high temperature, 1280 to 1330° C.

2. It must be a conductor of electricity with a fairly high resistance.

Platinum has been used for the material, but, as we shall see, its temperature cannot be maintained at a value high enough to make the lamp as efficient as when carbon is used. Nearly all attempts to substitute another substance in place of carbon have failed, and the few lamps which are partially successful will be treated under the head of special lamps. The nature of the carbon employed in incandescent lamps has, however, been much improved over the first forms, and the method of manufacture will be treated next.

MANUFACTURE OF INCANDESCENT LAMPS.

Preparation of the Filament. Cellulose, a chemical compound rich in carbon, is prepared by treating absorbent cotton with zinc chloride in proper proportions to form a uniform, gelatine-like mass. It is customary to stir this under a partial vacuum in order to remove bubbles of air which might be contained in it and destroy its uniformity. This material is then forced, "squirted," through steel dies into alcohol, the alcohol serving to harden the soft, transparent threads. These threads are then thoroughly washed to remove all trace of the zinc chloride, dried, cut to the desired lengths, wound on forms, and carbonized by heating to a high temperature away from air. During carbonization, the cellulose is transformed into pure carbon, the volatile matter being driven off by the high temperature to which the filaments are subjected. The material becomes hard and stiff, assuming a permanent form, shrinking in both length and diameter; the form being specially constructed so as to allow for this shrinkage. The forms are made of carbon blocks which are placed in plumbago crucibles and packed with powdered carbon; the crucibles are covered with loosely fitting carbon covers. The crucibles are gradually brought to a white heat, at which temperature the cellulose is changed to carbon, and then allowed to cool. After cooling, the filaments are removed, measured and inspected, and the few defective ones discarded.

In the early days, these filaments were made of cardboard or bamboo, and later of thread treated with sulphuric acid.

A few of the shapes of filaments now in use are shown in Fig. 1, the different shapes giving a slightly different distribution of light. The shapes here shown are designated as follows: A, U-shaped; B, single-curl; C, single-curl anchored; D, double-loop; E, double-curl; F, double-curl anchored.

Mounting the Filament. After carbonization, the filaments are mounted or joined to wires leading into the globe or bulb. These wires are made of platinum—platinum being the only substance, so far as known, that expands and contracts the same as glass with change in temperature and which, at the same time, will not be melted by the heat developed in the carbon. Since the bulb must remain air-tight, a substance expanding at a different rate from the glass cannot be used. Several methods of fastening the filament to the "leading in" wires have been used, such as forming a socket in the end of the wire, inserting the filament and then squeezing the socket tightly against the carbon, and the use of tiny bolts when cardboard filaments were used, but the pasted joint is now used almost exclusively. Finely powdered carbon is mixed with some adhesive compound, such as molasses, and this mixture is used as a paste for fastening the carbon to the platinum. Later, when current is sent through the joint, the volatile matter is driven off and only the carbon remains. This makes a cheap and, at the same time, a very efficient joint.

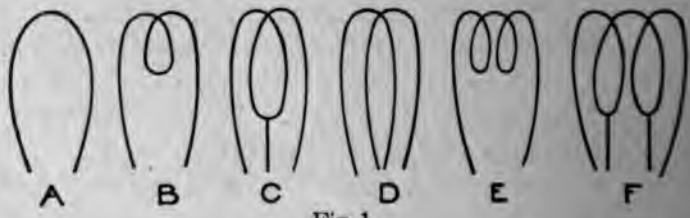
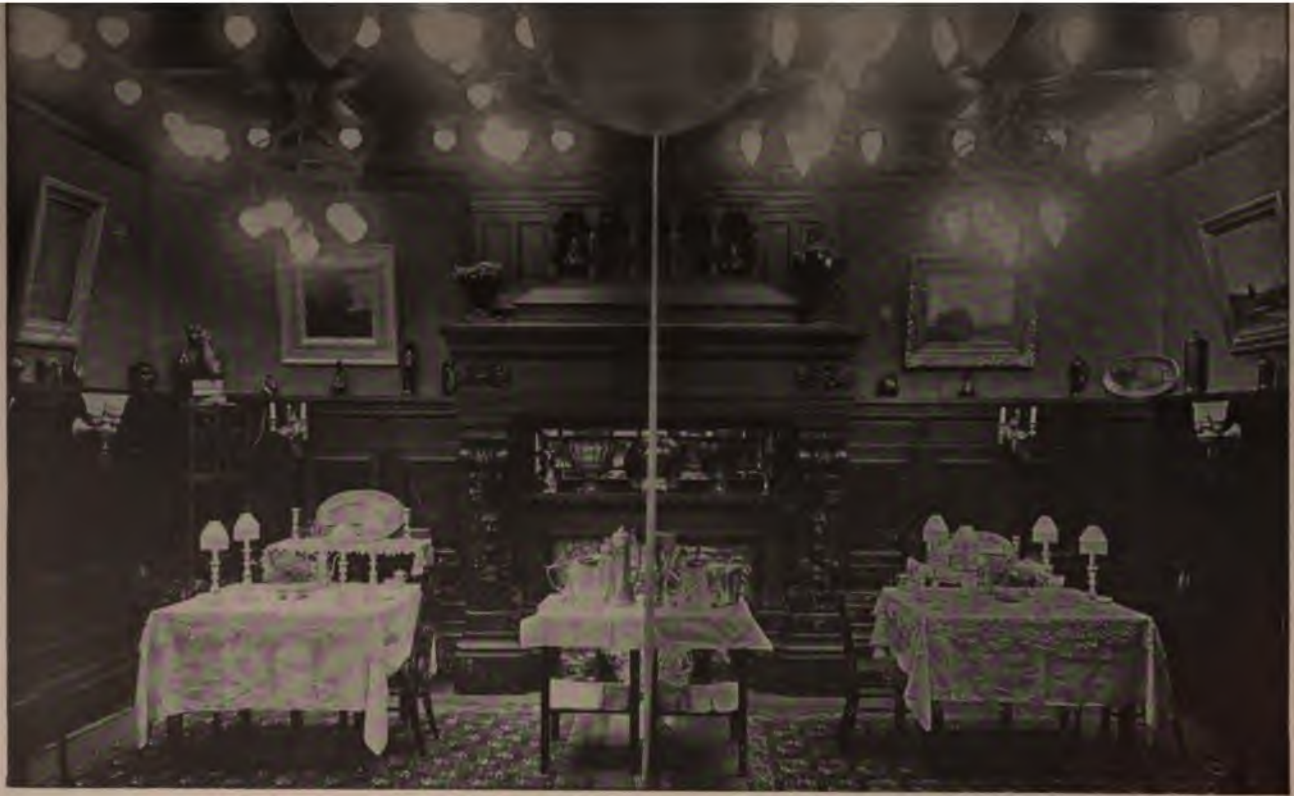


Fig. 1.

Flashing. Filaments, prepared and mounted in the manner just described, are fairly uniform in resistance, but it has been found that their quality may be much improved and their resistance very closely regulated by depositing a layer of carbon on the outside of the filament by the process of "flashing". By flashing is meant heating the filament to a high temperature when immersed in a hydrocarbon gas, such as gasoline vapor, under partial vacuum. Current is passed through the filament in this process to accomplish the heating. Gas is used, rather than a liquid, to prevent too heavy a deposit of the carbon. Coal gas is not recommended because the carbon, when deposited from this, has a dull black appearance. The effects of flashing are as follows:



HOLOPHANE EXHIBIT.

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1. The diameter of the filament is increased by the deposited rbon and hence its resistance is decreased. The process must be scontinued when the desired resistance is reached. Any little egularities in the filament will be eliminated since the smaller ctions, having the greater resistance, will become hotter than the mainder of the filament and the carbon is deposited more rapidly these points.

2. The character of the surface is changed from a dull black d comparatively soft nature to a bright gray coating which is much rder and which increases the life and efficiency of the filament.

Exhausting. After flashing, the filament is sealed in the lb and the air exhausted through the tube A in Fig. 2, which ows the lamp in different stages of its manufacture. The haustion is accomplished means of mechanical air ımps, supplemented by rengle or mercury pumps d chemicals. Since the gree of exhaustion must be gh, the bulb should be ated during the process so to drive off any gas which y cling to the glass. When emicals are used, as is now nost universally the case, e chemical is placed in the be A and, when heated, rves to take up much of the maining gas. Exhaustion necessary for several rea- ns:

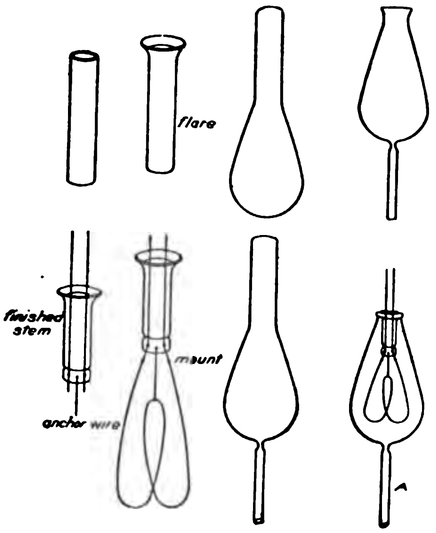


Fig. 2.

1. To avoid oxidization of the filament.
2. To reduce the heat conveyed to the globe.
3. To prevent wear on the filament due to currents or eddies in the gas.

After exhausting, the tube A is sealed off and the lamp com- eted for testing by attaching the base by means of plaster of ris. Fig. 3 shows some of the forms of completed incandescent nps.

Voltage and Candle-Power. Incandescent lamps vary in size from the miniature battery and candelabra lamps to those of several hundred candle-power, though the latter are very seldom used. The more common values for the candle power are 8, 16, 25, 32, and 50, the choice of candle-power depending on the use to be made of the lamp.

The voltage will vary depending on the method of distribution of the power. For what is known as parallel distribution, 110 or 220 volts are generally used. For the higher values of the voltage, long and slender filaments must be used, if the candle-power is to be low, and lamps of less than 16 candle-power for 220-volt circuits are not practical, owing to difficulty in manufacture. For series distribution, a low voltage and higher current is used, hence the filaments may be quite heavy. Battery lamps operate on from 4 to 24 volts, but the vast majority of lamps for general illumination are operated at or about 110 volts.

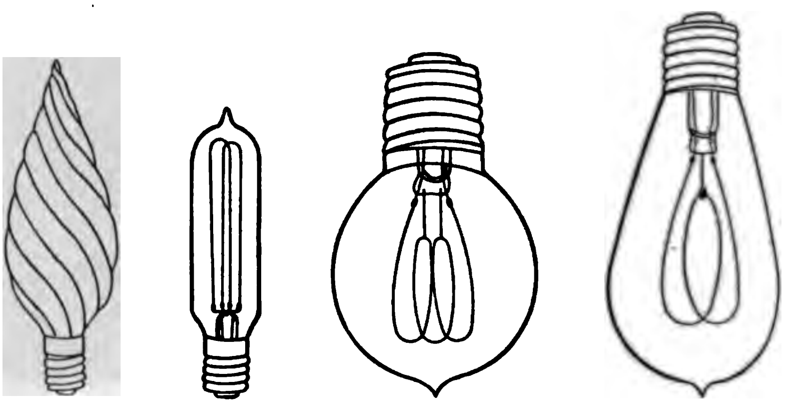


Fig. 3.

Efficiency. By the efficiency of an incandescent lamp is meant the power required at the lamp terminals per candle-power of light given. Thus, if a lamp giving an average horizontal candle-power of 16 consumes $\frac{1}{2}$ an ampere at 112 volts, the total number of watts consumed will be $112 \times \frac{1}{2} = 56$, and the watts per candle-power will be $56 \div 16 = 3.5$. The efficiency of such a lamp is said to be 3.5 watts per candle-power. "Watts economy" is sometimes used for "efficiency".

The efficiency of a lamp depends on the temperature at which the filament is run. This temperature is between 1280° and 1330° C, and the curve in Fig. 4 shows the increase of efficiency with the increase of temperature. The temperature attained by a filament depends on the rate at which heat is radiated and the amount of power supplied. The rate of radiation of heat is proportional to the area of the filament, the elevation in temperature, and the emissivity of the surface.

By emissivity is meant the number of heat units emitted from unit surface per degree rise in temperature above that of surrounding bodies. The bright surface of a flashed filament has a lower emissivity than the dull surface of an unheated filament, hence less energy is lost in heat radiation and the efficiency of the filament is increased.

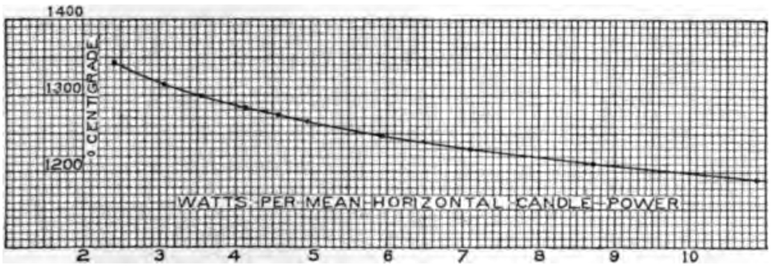


Fig. 4.

As soon as incandescence is reached, the illumination increases much more rapidly than the emission of heat, hence the increase in efficiency shown in Fig. 4. Were it not for the rapid disintegration of the carbon at high temperature, an efficiency higher than 3.1 watts could be obtained.

Relation of Life to Efficiency. By the useful life of a lamp is meant the length of time a lamp will burn before its candle-power has decreased to such a value that it would be more economical to replace the lamp with a new one than to continue to use it at its decreased value. A decrease to 80% of the initial candle-power is now taken as the point at which a lamp should be replaced, and the normal life of a lamp is in the neighborhood of 800 hours. To obtain the most economical results, lamps should always be replaced at the end of their useful life.

In ble I are given values of the efficiency and life of a 3.5-watt, 110-volt lamp for various voltages impressed on the lamp. ese values are plotted in Fig. 5. These curves show that a 3% increase of voltage on the lamp reduces the life by one-half, while an increase of 6% causes the useful life to fall to one-third its normal value. The effect is even greater when 3.1-watt lamps are used, but not so great with 4-watt lamps. From this we see that the regulation of the voltage used on the system must be very good if high efficiency lamps are to be used, and this regulation will dete he type of lamp to be installed.

Selection of Lamps. taking 3.1 watts per candle-power will give satisfaction o en the regulation of voltage is the best—practically a constan tage maintained at the normal voltage of the lamp.

TAB I.

Effects of Change in Voltage.

Standard 3.5 Watt Lamp.

Voltage Per Cent. of Normal.	Candle-Power Per Cent. of Normal.	Watts Per Candle-Power.	Life Per Cent. of Normal.	Deterioration Per Cent. of Normal.
90	53	5.36		
91	56	5.09		
92	61	4.85		
93	65	4.63		
94	69	4.44	394	25
95	73	4.26	310	32
96	78	4.09	247	44
97	83	3.93	195	51
98	88	3.78	153	65
99	94	3.64	126	79
100	100	3.5	100	100
101	106	3.38	84	118
102	111	3.27	68	146
103	116	3.16	58	173
104	123	3.05	47	211
105	129	2.95	39	253
106	137	2.85	31	316
107	143	2.76	26	380
108	152	2.68	21	474
109	159	2.60	17	575
110	167	2.53	16	637

Lamps of 3.5 watts per candle-power should be used when the regulation is fair, say with a maximum variation of 2% from the normal voltage.

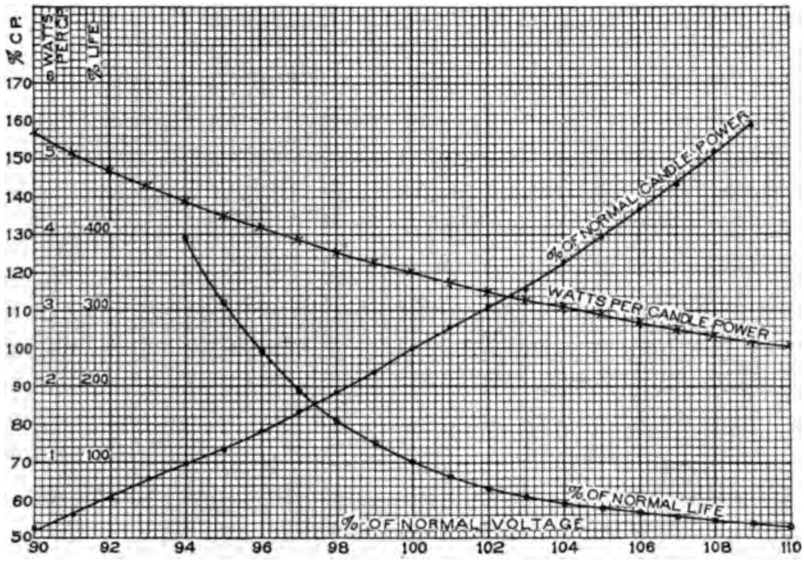


Fig. 5.

Lamps of 4 watts per candle-power should be installed when the regulation is poor. These values are for 110-volt lamps. A 220-volt lamp should have a lower efficiency to give a long life.

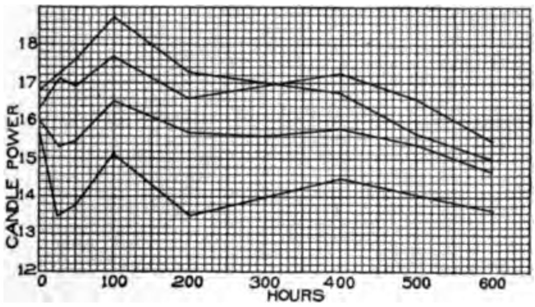


Fig. 6.

Lamps should always be renewed at the end of their useful life, this point being termed the "smashing-point", as it is cheaper to replace the lamp than to run it at the reduced candle-power. Some recommend running these lamps at a higher voltage, but that means at a reduced efficiency, and it is not good practice to do this.

Fig. 6 shows the life curves of a series of incandescent lamps. These curves show that there is an increase in the candle-power of some of the lamps during the first 100 hours, followed by a period during which the value is fairly constant, after which

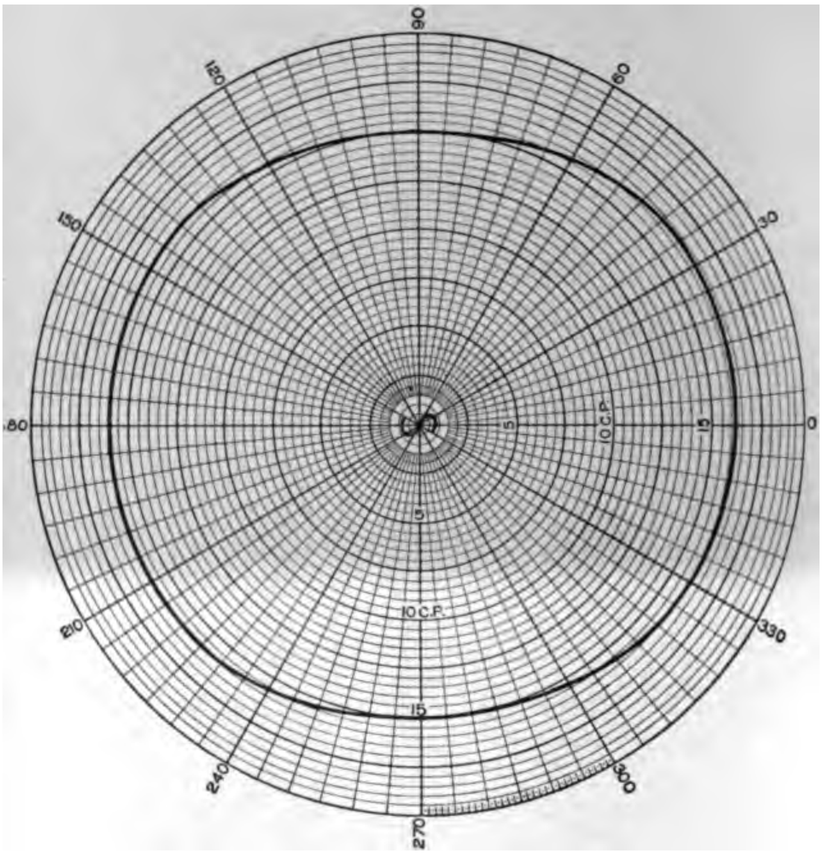


Fig. 7.

the light given by the lamp is gradually reduced to about 80% of the initial candle-power.

DISTRIBUTION OF LIGHT.

In Fig. 1 are shown various forms of filaments used in incandescent lamps, and Figs. 7 and 8 show the distribution of light from a single-loop filament of cylindrical cross-section.

ig. 7 shows the distribution of light in a horizontal plane, the mp being mounted in a vertical position, and Fig. 8 shows the stribution in a vertical plane. By changing the shape of the ament, the light distribution is varied. A mean of the readgs taken in the horizontal plane forms the *mean horizontal ndle-power*, and this candle-power rating is the one generally ssumed for the ordinary incandescent lamp. A mean of the adings taken in a vertical plane gives us the mean vertical ndle-power, but this value is of little use.

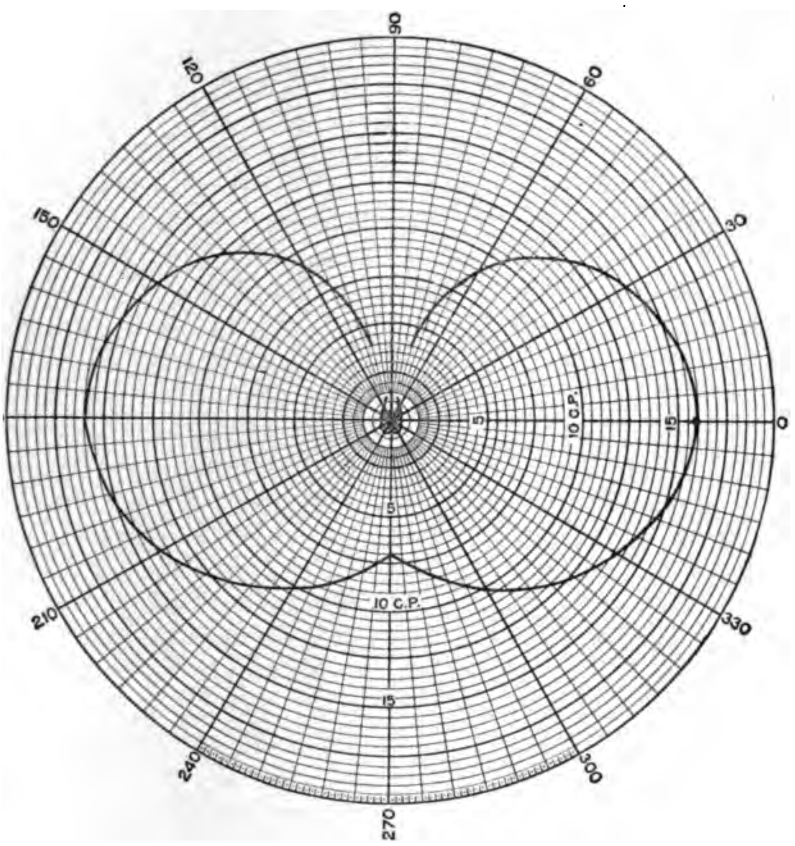


Fig. 8.

Mean Spherical Candle-Power. When comparing lamps hich give an entirely different light distribution, the mean horizonver does not form a proper basis for such comparison, and the mean spherical or the mean hemispherical candle-power is used instead. By mean spherical candle-power is meant a mean value of the light taken in all directions. The methods for determining this will be taken up under *photometry*. The mean hemispherical candle-power has reference, usually, to the light given out below the horizontal plane.

ARC LAMPS.

The Electric Arc. Suppose two carbon rods are connected in an electric circuit, and the c losed by touching the tips of these rods together; on separ he carbons again the circuit will not be broken, provided ce between the carbons be not too great, but will be maintai ough the arc formed at these points. This phenomenon, w the basis of the arc light, was first observed on a large scale Humphrey Davy, who used a f 2,000 cells and produced an a tween charcoal points four inches ap

he incandescence of the carbons across which an arc is maintained, together with the arc itself, forms the source of light for all arc lamps, it will be well to study the nature of the arc. Fig. 9 shows the general appearance of an arc between two carbon electrodes when maintained by direct current.

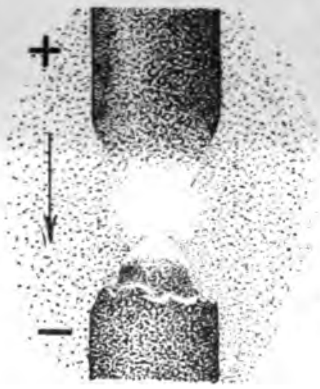


Fig. 9.

Here the current is assumed as passing from the top carbon to the bottom one as indicated by the arrow and signs. We find, in the direct-current arc, that the most of the light issues from the tip of the positive carbon, or electrode, and this portion is known as the *crater* of the arc. This crater has a temperature of from 3,000 to 3,500° C, the temperature at which the carbon vaporizes, and gives fully 80 to 85% of the light furnished by the arc. The negative carbon becomes pointed at the same time that the positive one is hollowed out to form the crater, and it is also incandescent but not to as great a degree as the positive carbon.

Between the electrodes there is a band of violet light, the arc proper, and this is surrounded by a luminous zone of a golden yellow color. The arc proper does not furnish more than 5% of the light emitted.

The carbons are worn away or consumed by the passage of the current, the positive carbon being consumed about twice as rapidly as the negative.

The light distribution curve of a *direct-current arc*, taken in a vertical plane, is shown in Fig. 10. Here it is seen that the maximum amount of light is given off at an angle of about 50° from the vertical, the negative carbon shutting off the rays of light that are thrown directly downward from the crater.

If alternating current is used, the upper carbon becomes positive and negative alternately, and there is no chance for a crater to be formed, both carbons giving off the same amount of light and being consumed at about the same rate. The light distribution curve of an *alternating-current arc* is shown in Fig. 11.

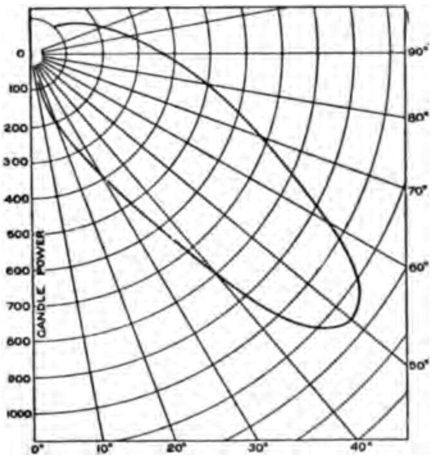


Fig. 10.

Arc Lamp Mechanisms. In a practical lamp we must have not only a pair of carbons for producing the arc, but also means for supporting these carbons, together with suitable arrangements for leading the current to them and for maintaining them at the proper distance apart. The carbons are kept separated the proper distance by the operating mechanisms which must perform the following functions:

1. The carbons must be in contact, or be brought into contact, to start the arc when the current first flows.
2. They must be separated at the right distance to form a proper arc immediately afterward.
3. The carbons must be fed to the arc as they are consumed.
4. The circuit should be open or closed when the carbons are entirely consumed, depending on the method of power distribution.

The feeding of the carbons may be done by hand, as is the case in some stereopticons using an arc, but for ordinary illumination the striking and maintaining of the arc must be automatic. It is made so in all cases by means of solenoids acting against the force of gravity or against springs. There are an endless number

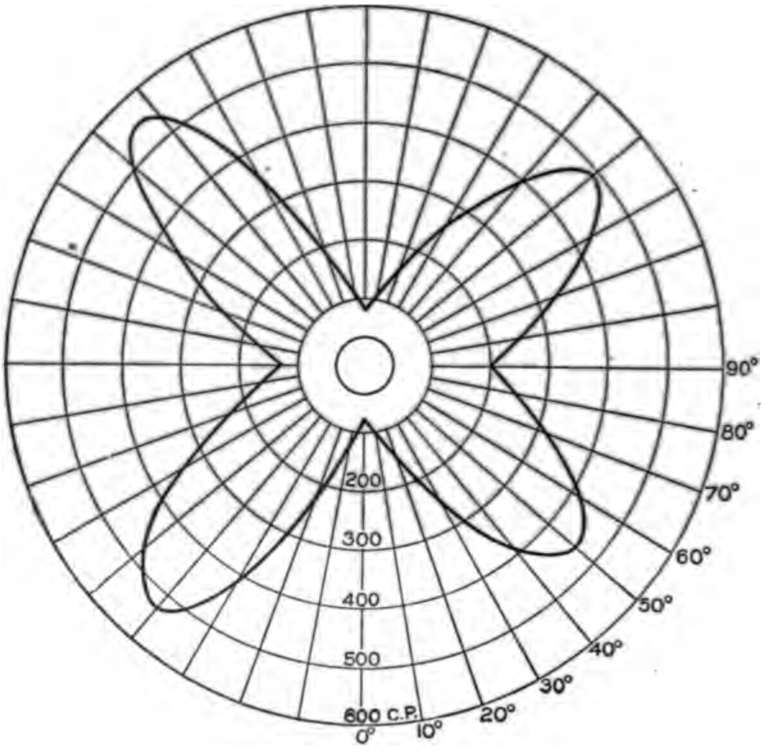


Fig. 11.

of such mechanisms, but a few only will be described here. They may be roughly divided into three classes:

1. Shunt Mechanisms.
2. Series Mechanisms.
3. Differential Mechanisms.

In **Shunt Lamps**, the carbons are held apart before the current is turned on, and the circuit is closed through a solenoid connected in across the gap so formed. All of the current must pass through this coil at first, and the plunger of the solenoid is arranged to draw the carbons together, thus starting the arc. The pull of the solenoid and that of the springs are adjusted to maintain the arc at its proper length.

Such lamps have the disadvantage of a high resistance at the start—450 ohms or more—and are difficult to start on series circuits, due to the high voltage required. They tend to maintain a constant voltage at the arc, but do not aid the dynamo in its regulation, so that the arcs are liable to be a little unsteady.

With the **Series-Lamp Mechanism**, the carbons are together when the lamp is first started and the current, flowing in the series coil, separates the electrodes, striking the arc. When the arc is too long, the resistance is increased and the current lowered so that the pull of the solenoid is weakened and the carbons feed together. This type of lamp can be used only on constant-potential systems.

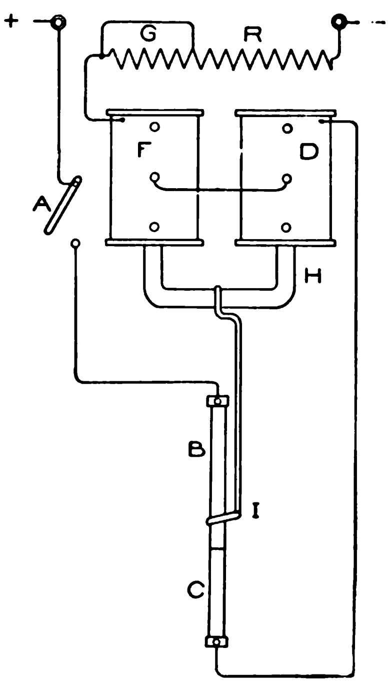


Fig. 12.

Fig. 12 shows a diagram of the connection of such a lamp. This diagram is illustrative of the connection of one of the lamps manufactured by the Western Electric Company, for use with direct current on a constant-potential system. The symbols + and — refer to the terminals of the lamp, and the lamp must be so connected that the current flows from the top carbon to the bottom one. R is a series resistance, adjustable for different voltages by means of the shunt G. F and D are the controlling solenoids connected in series with the arc. B and C are the positive and negative carbons respectively, while A is the switch for turning the current on and off. H is the plunger of the solenoids and I the carbon clutch, this being what is known as a "carbon feed" lamp. The carbons are together when A is first closed, the current is excessive, and the plunger is drawn up into the solenoids, lifting the carbon B until the resistance of the arc lowers the current to such a value that the pull of the solenoid just counterbalances the weight of the plunger and carbon. G must be so adjusted that this point is reached when the arc is at its normal length.

In the **Differential Lamp,** the series and shunt mechanisms are combined, the carbons being together at the start, and the series coil arranged so as to separate them while the shunt coil is connected across the arc, as before, to prevent the carbons from being drawn too far apart. This amp operates only over a low-urrent range, but it tends to aid the generator in its regulation.

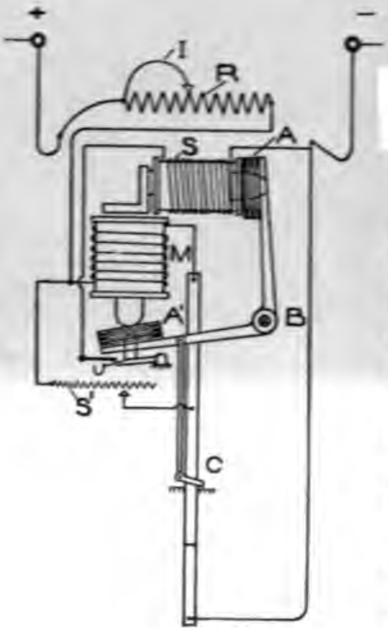


Fig. 13.

Fig. 13 shows a lamp having a ifferential control, this also being the diagram of a Western Electric Company arc lamp for direct-current, constant-potential system. Here S represents the shunt coil and M the series coil, the armature of the two magnets A and A' being attached to a bell-crank, pivoted at B, and attached to the carbon clutch C. The pull of coil S tends to lower the carbon while that of M raises the carbon, and the two are so adjusted that equilibrium is reached when the arc is of the proper length. All of the lamps are fitted with an air dashpot or some damping device to prevent too rapid movements of the working parts.

The methods of supporting the carbons and feeding them to the arc may be divided into two classes:

1. Rod feed.
2. Carbon feed.

Lamps using a **Rod Feed** have the upper carbons supported by a conducting rod, and the regulating mechanism acts on this rod,

·ent being fed to the rod by means of a sliding contact. shows the arrangement of this type of feed. The rod is ıt R, the sliding contact at B, and the carbon is attached to at C.

ese lamps have the advantage that carbons, which do not uniform cross-section or smooth exterior, may be used, but ssess the disadvantage ; very long in order to ıodate the rod. The ıt also be kept clean so ıake a good contact e brush.

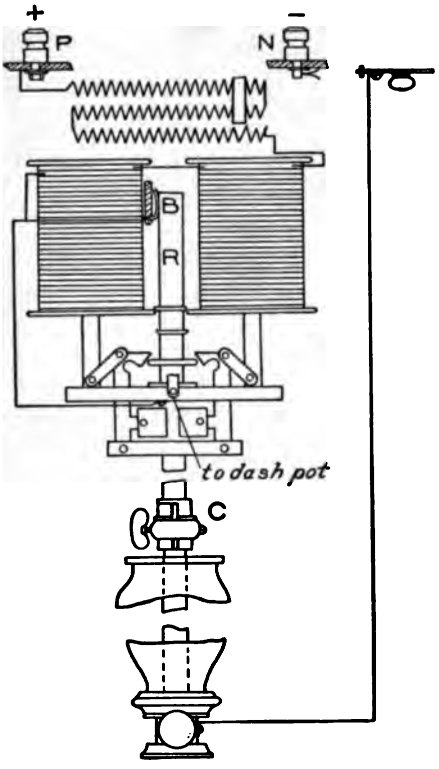


Fig. 14.

ırbon-Feed lamps the ing mechanism acts ə carbons directly ı some form of clutch is shown at C in Fig. ıis clamp grips the car- ıen it is lifted, but the carbon to slip ı it when the tension ;ed. For this type of he carbon must be ; and have a uniform ıection as well as a ı exterior. The cur- ıy be led to the carbon ıns of a flexible lead hort carbon holder.

ıle-Carbon Lamps. In ı increase the life of the orm of arc lamp without using too long a carbon, the carbon type was introduced. This type uses two sets of ı, both sets being fed by one mechanism so arranged that one pair of the electrodes is consumed the other is put rvice. With the introduction of the enclosed arcs, this f lamp is rapidly disappearing, although a few are still

Arc lamps are constructed to operate on *Direct Current* or *Alternating Current* systems when connected in *Series* or in *Multiple*. They are also made in both the *Open* and the *Enclosed* forms, but almost all of the lamps operating on alternating current or on constant-potential, direct current are enclosed.

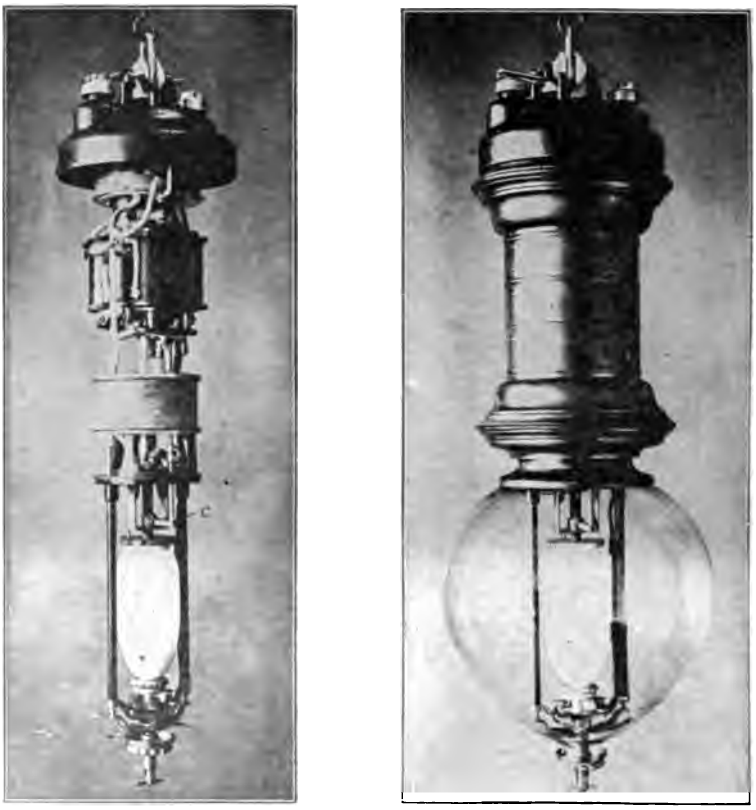


Fig. 15.

By an *Open Arc* is meant an arc lamp in which the arc is exposed to the atmosphere, while in the *Enclosed Arc* an inner or enclosing globe surrounds the arc, and this globe is covered with a cap which renders it nearly air-tight. Fig. 15 is a good example of an enclosed arc as manufactured by the General Electric Company.

Open Arcs for direct-current systems were the first to be used to any great extent, and they are used considerably at present, although they are being rapidly replaced by the enclosed types or the alternating-current systems. They are always connected in series, and are run from some form of special arc machine, a description of which may be found in "Types of Dynamo Electric Machinery".

Each lamp requires in the neighborhood of 50 volts for its operation, and, since the lamps are connected in series, the voltage of the system will depend on the number of lamps; therefore, the number of lamps that may be connected to one machine is limited by the maximum allowable voltage on that machine. By special construction as many as 125 lamps are run from one machine, but even this size of generator is not so efficient as one of greater capacity. Such generators are usually wound for 6.6 or 9.6 amperes. Since the carbons are exposed to the air at the arc, they are rapidly consumed, requiring that they be renewed daily for this type of lamp.

Enclosed Direct-Current Arc Lamps for series systems are constructed much the same as the open lamp, and are controlled by either shunt or differential mechanism. They require a voltage from 68 to 75 at the arc, and are usually constructed for from 5 to 6.8 amperes. They also require a constant-current generator.

Arc Lamps for Constant-Potential direct-current systems must have some resistance connected in series with them to keep the voltage at the arc at its proper value. This resistance is made adjustable so that the lamps may be used on any circuit. Its location is clearly shown in Fig. 15, one coil being located above, the other below the operating solenoids.

Arc Lamps for Alternating Currents do not differ greatly in construction from the direct-current arcs. When iron or other metal parts are used in the controlling mechanism, they must be laminated or so constructed as to keep down induced or eddy currents which might be set up in them. For this reason the metal spools, on which the solenoids are wound, are slotted at some point to prevent them from forming a closed secondary to the primary formed by the solenoid winding. On constant potential circuits a reactive coil is used in place of a part of the resistance for cutting down the voltage at the arc.

Interchangeable Arc Lamps are manufactured which may be readily adjusted so as to operate on either direct or alternating current, and on voltages from 110 to 220. Two lamps may be run in series on 220-volt circuits.

The distribution of light, and the resulting illumination for the different lamps just considered, will be taken up later. Aside from the distribution and quality of light, the enclosed arc has the advantage that the carbons are not consumed so rapidly as in the open lamp because the oxygen is soon exhausted from the inner globe and the combustion of the carbon is greatly decreased. They will burn from 80 to 100 hours without re-trimming.

TABLE 2.

		Watts Consumed.			Mean Intensity in H. U.			Mean Watts.		
					Spherical.		Lower Hemi-spherical	Spherical H. U.		Lower Hemi-spherical
D. C. Lamp.	Current.	In Lamp.	In Arc.	Mechanism.	Op. Outer.	Clear Outer	Clear Outer.	Op. Outer.	Clear Outer.	Clear Outer.
						235	332		2.37	1.66
1	5.01	551	401	150	172	256*	362*	3.10	2.18*	1.52*
3	5.08	559	406	252	195	216	282	2.85	2.60	1.99
4	4.76	524	381	143	127	139	208	4.12	3.76	2.52
5	4.16†	458	333	125	154	174	221	2.96	2.63	2.07
7	4.76	524	381	143	203	333	317	2.63	2.20	1.65
9	4.84	532	387	145	182	226	281	2.83	2.38	1.89
10	4.99	549	399	150	202	242	309	2.74	2.24	1.77
12	4.87	536	390	146	178	195	230	3.05	2.66	2.33
Mean	4.9	529	384	144	176	207	272	3.03	2.60	1.98

A. C. Lamp.	Current.	In Lamp.	Power Factor Lamp.	In Arc.	Power Factor Arc.	Mechanism.						
101	6.40	448	.63	340	.82	108	127	141	206	3.52	3.17	2.17
								203	236		2.26	1.94
102	6.79	459	.61	375	.73	84	146	176†	226†	3.31	2.60†	1.72†
103	5.89	424	.65	344	.75	80	116	130	147	3.66	3.15	2.88
105	6.20	414	.61	382	.80	32	128	187	219	3.24	2.20	1.89
								153	169		2.56	2.23
106	6.12	378	.56	298	.70	80	132	182†	284	2.82	2.19†	1.48†
108	6.48	457	.64	383	.80	74.5	133	175	211	3.20	2.61	2.16
110	6.18	339	.49	276	.72	63	140*	126	143	2.41*	2.68	2.37
Mean	6.29	417	.60	342	.76	74.5	130	159	190	3.31	2.66	2.23

*Condition of no outer globe. †Condition with shade on lamp. H. U Hefner Units.

Rating of Arc Lamps. Open arcs have been classified as follows:

Full Arcs, 2,000 candle-power taking 9.5 to 10 amps. or 450–480 watts.
Half Arcs, 1,200 candle-power taking 6.5 to 7 amps. or 325–350 watts.

These candle-power ratings are much too high, and run more nearly 1,200 and 700, respectively, for the point of maximum intensity and less than this if the mean spherical candle-power be taken. For this reason, the ampere or watt rating is now used to indicate the power of the lamp. Enclosed arcs use from 3 to 6.5 amperes, but the voltage at the arc is higher than for the open lamp. Table 2 gives some data on enclosed arcs on constant-potential circuits.

Efficiency. The efficiency of arc lamps is given as follows:

Direct Current Arc (enclosed) 2.9 watts per candle-power.
Alternating Current Arc (enclosed) 2.95 watts per candle-power.
Direct Current Arc (open) .6–1.25 watts per candle-power.

Arc-Lamp Carbons are either moulded or forced from a product known as petroleum coke or from similar materials such as lampblack. The material is thoroughly dried by heating to a high temperature, then ground to a fine powder and combined with some substance such as pitch which binds the fine particles of carbon together. After this mixture is again ground it is ready for moulding. The powder is put in steel moulds and heated until it takes the form of a paste, when the necessary pressure is applied to the moulds. For the forced carbons, the powder is formed into cylinders which are placed in machines which force the material through a die so arranged as to give the desired diameter. The forced carbons are often made with a core of some special material, this core being added after the carbon proper has been finished. The carbons, whether moulded or forced, must be carefully baked to drive off all volatile matter. The forced carbon is always more uniform in quality and cross-section, and is the type of carbon which must be used in the carbon feed lamp. The adding of a core of a different material seems to change the quality of light, and being more readily volatilized, keeps the arc from wandering.

Plating of carbons with copper is sometimes resorted to for moulded forms for the purpose of increasing the conductivity, and, by protecting the carbon near the arc, prolonging the life.

SPECIAL LAMPS.

Under this heading may be considered all lamps which do not use carbon as the incandescent material, as well as some lamps

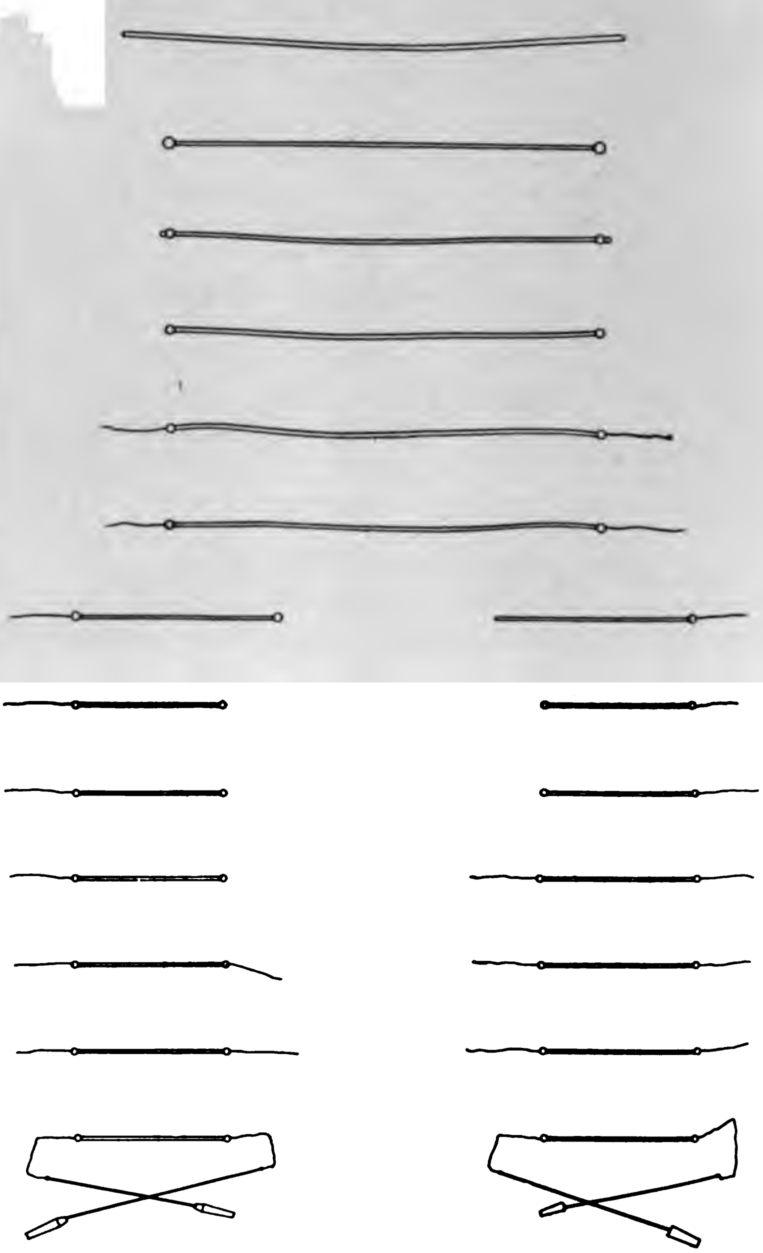


Fig. 16.

which use carbon in conjunction with other materials. The first of these lamps, or the one at present most widely used, is the Nernst Lamp.

The Nernst Lamp is an incandescent lamp using for the incandescent material certain oxides of the rare earths. The oxide is mixed in the form of a paste, then squirted through a die into a string which is subjected to a roasting process forming the filament or *glower* material of the lamp. The glowers are cut the desired length and platinum terminals attached. The attachment of these terminals to the glowers is a very important process in the manufacture of the lamp, and is accomplished by fusing the ends of the glower and the platinum lead into small beads, and, when the two are brought into contact, the platinum is sucked up into the glower head, forming a very neat and efficient connection. Fig. 16 shows several completed glowers.

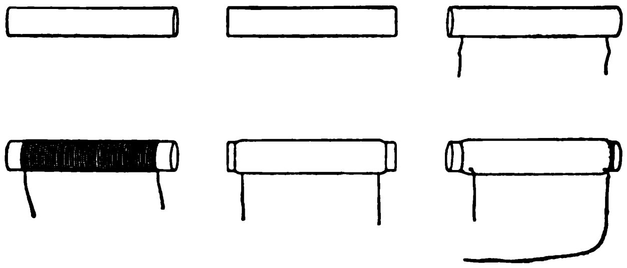
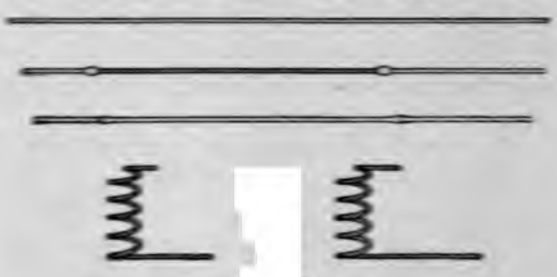


Fig. 17.

As the glower is a non-conductor when cold, some form of *heater* is necessary to bring it up to a temperature at which it will conduct. Two forms of heater are used, the first being formed of fine platinum wire wound over a porcelain tube as a support and covered with porcelain paste to prevent deterioration as much as possible. These "heater tubes", as they are called, are mounted just above the glowers in the finished lamp. The second form of heater is known as the "spiral heater", and this is also made of fine platinum wire wound on a porcelain rod and covered with paste, the rod being then formed on a mandrel to the desired shape. Figs. 17 and 18 show the two forms of heaters.

The heating device is conneeted across the circuit when the lamp is first turned on, and it must be cut out of circuit automatically [illegible] the glower becomes a conductor, otherwise the heater would [illegible] be destroyed. This automatic *cut-out* is operated by means [illegible] electromagnet so arranged that current flows through its coil as soon as the glower conducts and opens a form of silver



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contact cutting out the heater. The heater circuit is normally kept closed by the force of gravity so that the lamps will operate only in one position. A successful form of universal cut-out, that is, one which will operate when the lamp is in any position, has not yet been put on the market, though experiments with this type are being made.

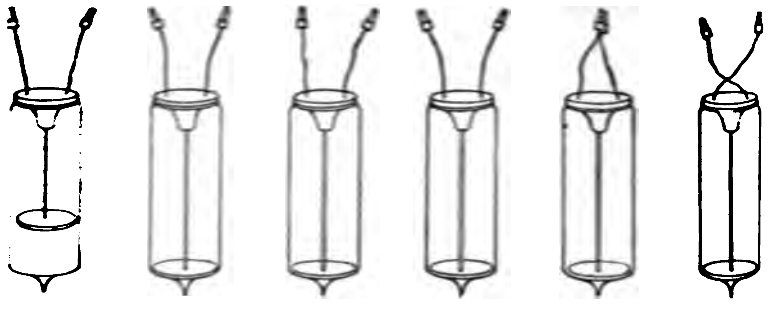


Fig. 19.

The conductivity of the glower increases with its temperature; hence, if used on a constant-potential circuit directly, its temperature would continue to increase, due to the greater current flowing, until the glower was destroyed. To prevent this increase of current, a *ballast resistance* of fine iron wire is connected in series with the glower. As is well known, the resistance of iron wire increases quite rapidly with increase of temperature, and this resistance is so adjusted that the resistance of the combined circuit reaches a constant value when the current is of the proper strength. The iron wire must be protected from the air to prevent oxidization and too rapid temperature changes, and, for this reason, it is mounted in a glass bulb filled with hydrogen. Hydrogen has been selected for this purpose because it is an inert gas and conducts the heat from the ballast to the walls of the bulb better than other gases. Fig. 19 shows the form of bulb which contains the ballast.

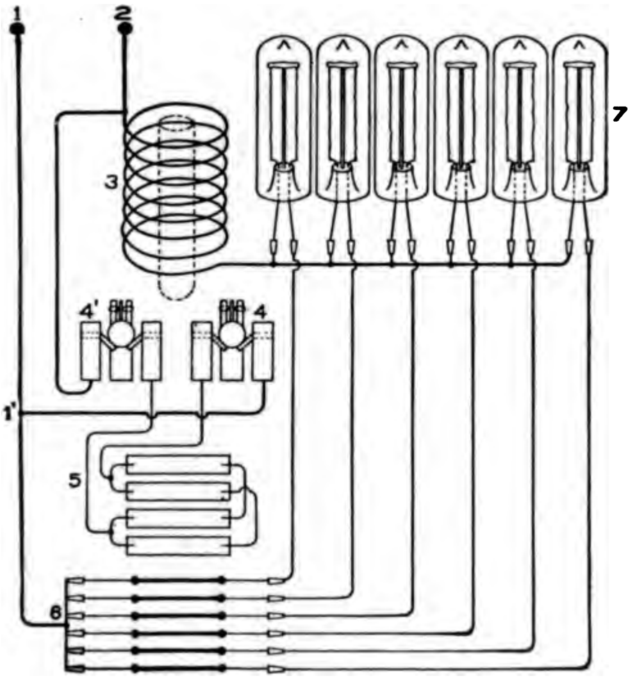


Fig. 20.

All of the parts enumerated, namely, glower, heater, cut-out and ballast, are mounted in a suitable manner, the smaller lamps having but one glower and arranged to fit an incandescent lamp socket, while the larger types have as many as six glowers and are arranged to be supported in a manner similar to arc lamps. All of the parts are interchangeable and may be easily renewed.

Fig. 20 shows the complete connections of a six-glower lamp. Current enters the lamp at terminal 1 (or 2), passes through the

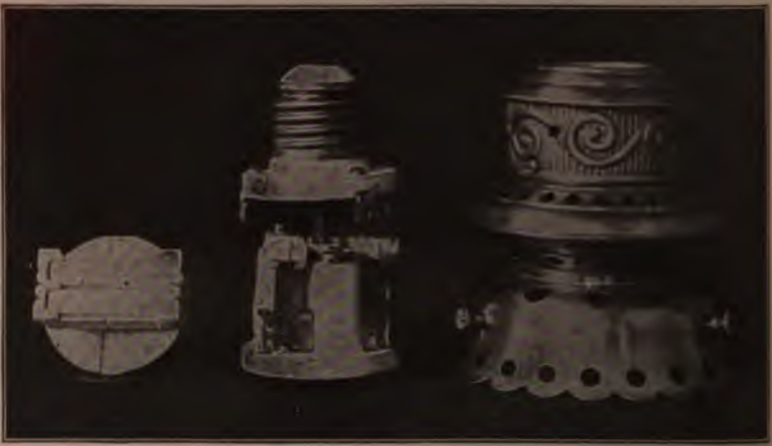


Fig. 21.

contacts of the cut-out 4, to the heater circuit 5, then to the contacts 4′ and to terminal 2. When the glowers become hot enough to conduct, the current divides at 1′, part of it going through the

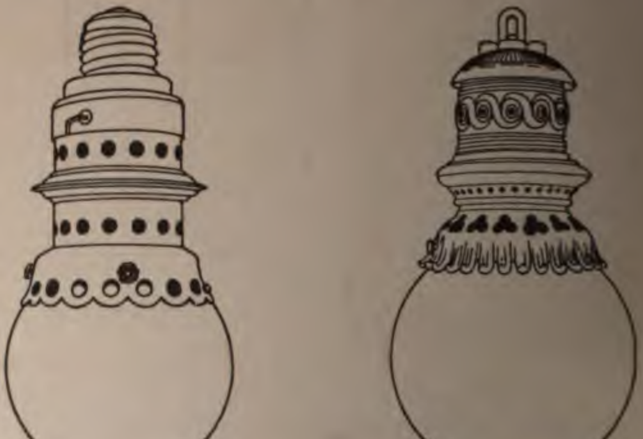


Fig. 23.

glowers 6, the ballast 7, and the cut-out coil 3 to terminal 2. By the time the current in the glower has reached its normal value, the contacts at 4 and 4′ have opened, cutting out the heater coils entirely. The heaters are so arranged that if one is destroyed, the other two will heat the glowers as quickly as possible.

Fig. 21 shows the parts of a single-glower lamp with the exception of the globe. Fig. 22 illustrates a six-glower street lamp. Fig. 23 shows lamps for inside use completely assembled Fig. 24 shows a glower and spiral heater so mounted that the two may be very readily replaced. This type is used on some of the very latest forms of lamps put on the market by the Nernst Lamp Company of Pittsburg, which company controls the manufacture of these lamps in the United States.

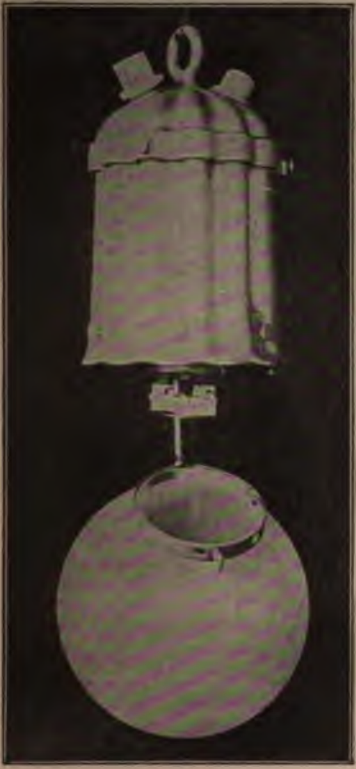


Fig. 22.

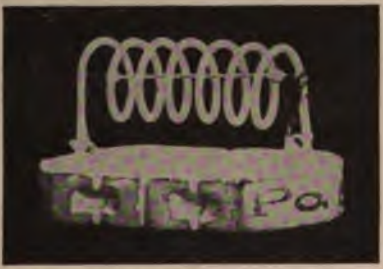


Fig. 24.

This type of lamp is used extensively only on alternating-current circuits at a frequency of about 60 cycles, and preferably at 220 volts, as the efficiency is better at this voltage, due to less energy being consumed in the ballast. Series lamps, and lamps operated on direct current, are still in the experimental stage.

The advantages claimed for the Nernst lamp are increased efficiency, a good color of light, and a good light distribution. The efficiency varies with the type and the voltage used, as well as with the direction in which the candle-power is measured and the type of globe used. For a 100-hour run on a two-glower, 220-volt lamp using a 6-inch light sand-blasted globe, the watts varied from 170 to 158, while the mean hemispherical candle-power varied from 67.8 to 50.8, giving an efficiency from 2.5 to 3.1 watts per mean hemispherical candle-power; showing an efficiency better than the incandescent but not so good as the arc lamp.

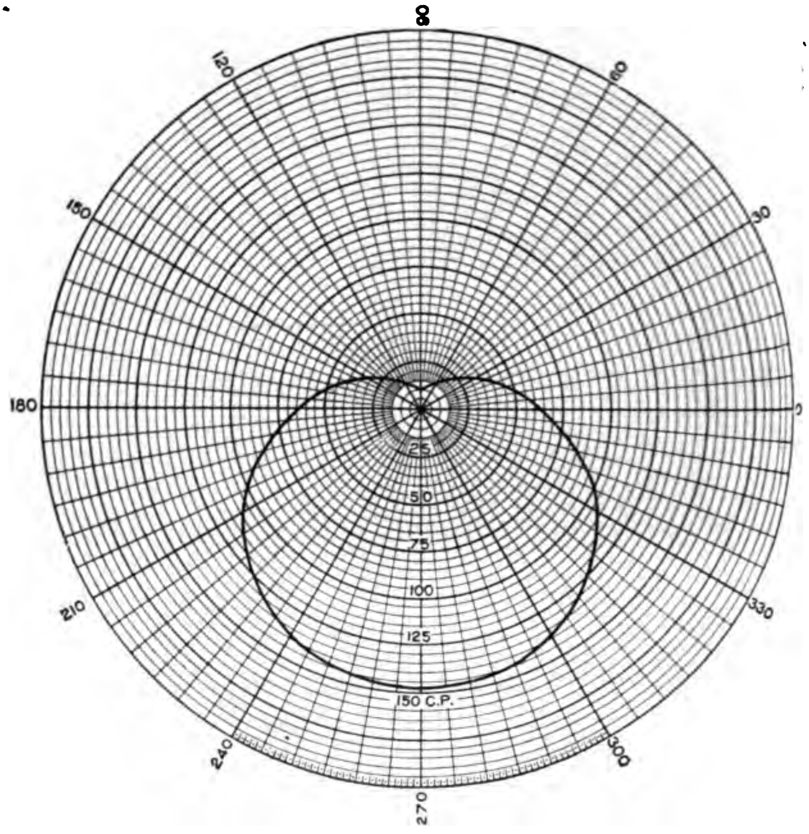


Fig. 25.

Fig. 25 shows two distribution curves for Nernst lamps.

To give the best results, lamps using the tube heaters must be cleaned regularly at the intervals of about 100 hours of burning. The spiral heaters are not cleaned, but are renewed at the end of the useful life of the glower. The light given by these lamps is very white in color, and the use of sand-blasted or alabaster globes reduces its intense brilliancy.

Osmium Lamps. Osmium has been experimented on as a substance to replace carbon in the ordinary incandescent lamp, and so far very efficient lamps have been constructed using this material, but the voltage is low, due to the low resistance of the material and the difficulty of making a filament fine enough to give the desired resistance for higher voltages. At 25 volts, lamps are constructed giving an efficiency of 1.5 to 1.7 watts per candle-power, and with a life comparable with that of a 3.5-watt incandescent lamp. The low voltage makes this lamp undesirable for parallel distribution systems.

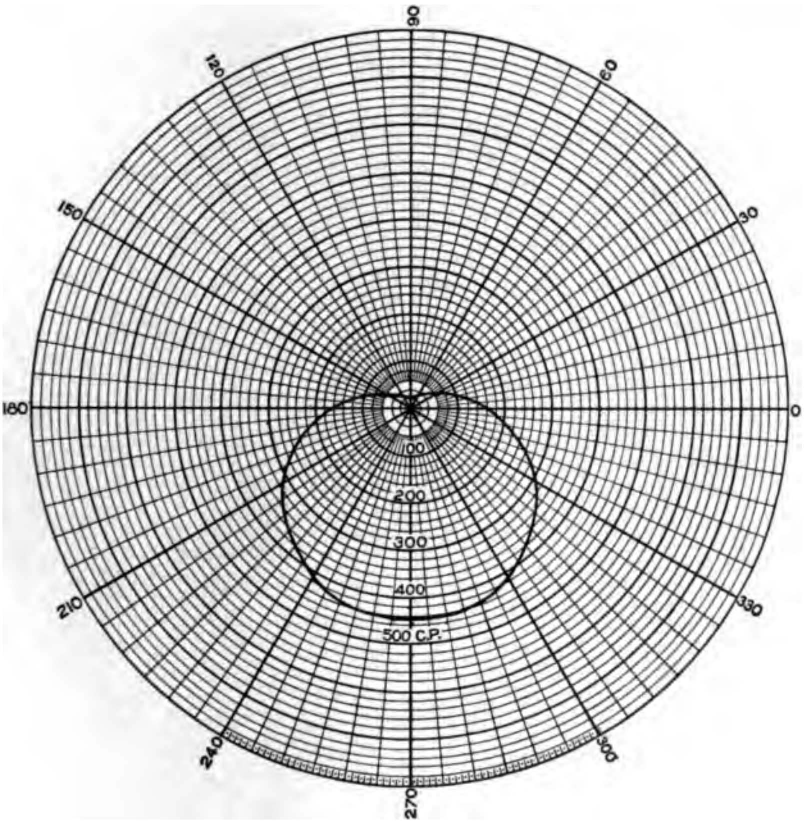


Fig. 25.

The Bremer Arc Lamp is one of the most favorable of several modifications of the arcs which have been proposed. This lamp uses very slender carbons having a core made of refractory oxides such as silica, lime, or magnesia. An efficiency of .1 to .4 watts per candle-power (mean spherical) has been claimed for this type of lamp, but it is still in the experimental stage.

The Mercury Vapor Lamp. Probably the Cooper Hewitt, or Mercury Vapor Lamp, is the only other special lamp deserving mention here. This lamp is being introduced to quite an extent where the quality of the light is not of so much importance. In this lamp, mercury vapor, rendered incandescent by the passage of an electric current, forms the source of light. One electrode is formed of mercury and the other may be of mercury or iron. In the more common type of lamp, these electrodes are mounted at the end of a long glass tube which has been very carefully exhausted. Fig. 26 shows such a lamp constructed for a 110-volt circuit. Dimensions of this lamp are as follows:

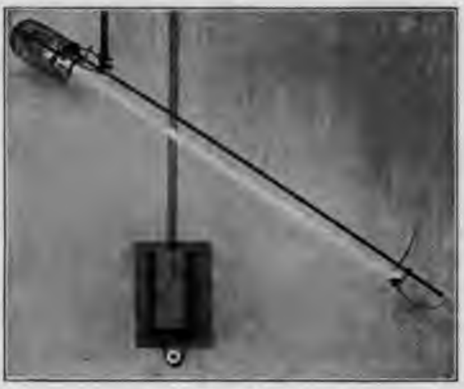


Fig. 26.

	For 100 Volts.	For 120 Volts.
Length of light-giving tube.......	43 inches.	49 inches.
Length over all..................	50 inches.	56 inches.
Diameter.........................	1 inch.	

Current 3 to 3.5 amperes.
Candle Power at 120 volts, 750.
Life (average), 1,600 hours.

The mercury vapor, at the start, may be formed in two ways. First, the lamp may be tipped so that a stream of mercury makes contact between the two electrodes and mercury is vaporized when the stream breaks. Second, by means of a high inductance and a quick break switch; a very high voltage, sufficient to pass current from one electrode to the other, is induced and the conducting vapor formed. The lamp, as now manufactured, will operate only on direct current, but the alternating-current lamp is being developed.

Fig 27 is a diagram of a lamp connected for starting by the quick-break method, while Fig. 28 shows two 55-volt lamps connected in series on a 110-volt circuit, and arranged to be started by tipping. A steadying resistance and reactance are connected as shown in the diagram, the two being mounted on one base which may readily be attached to the wall as shown in Fig. 26.

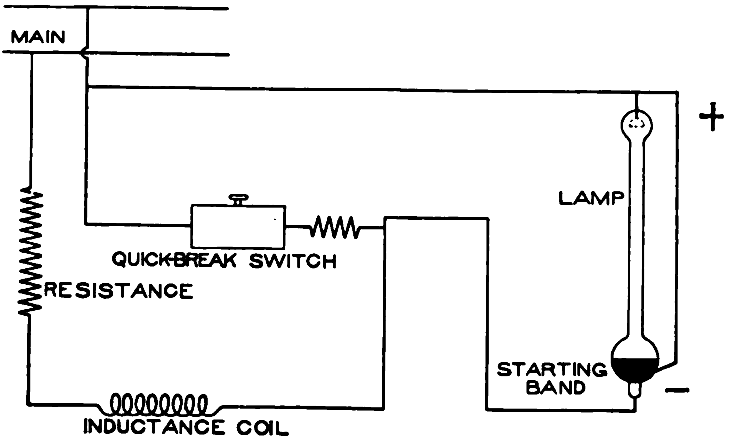


Fig. 27.

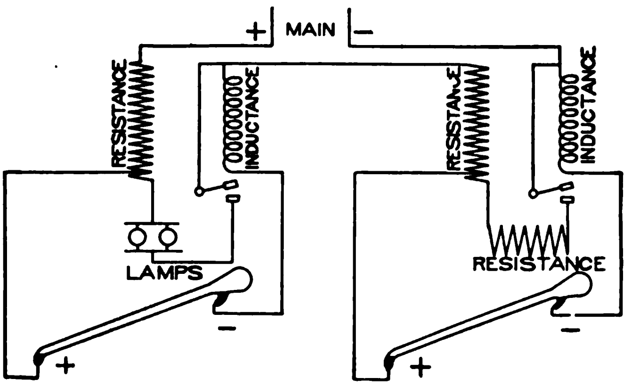


Fig. 28.

The mercury vapor lamp is not made in small sizes for ordinary voltages, and its light is very objectionable for the purpose of distinguishing color, as there is an entire absence of red rays.

This absence of the red light makes the illumination one that is very easy on the eyes but, on account of the color, its use is limited to the lighting of shops, offices, and drafting rooms, or in display windows where the goods shown are not changed in appearance by its color. It is also coming into use to a large extent in photographic work on account of the actinic properties of its light.

POWER DISTRIBUTION.

The question of power distribution for electric lamps and other appliances is taken up fully in the section on that subject, therefore it will be treated very briefly here. The systems may be divided into:

1. Series Distribution Systems.
2. Multiple-Series or Series-Multiple Systems.
3. Multiple or Parallel Systems.

They apply to both alternating and direct current.

The Series System is the most simple of the three; the lamps, as the name indicates, being connected in series as shown in Fig. 29. A constant load is necessary if a constant potential is to be used. If the load is variable, a constant-current generator, forms of which are described in "Types of Dynamo-Electric Machinery", or a special regulating device is necessary. Such devices are constant-current transformers and constant-current regulators as applied to alternating-current circuits.

The series system is used mostly for arc and incandescent lamps when applied to street illumination. Its advantages are simplicity and saving of copper. Its disadvantages are high voltage, fixed by the number of lamps in series; size of machines is limited since they cannot be insulated for voltage above about 6,000; a single open circuit shuts down the whole system.

Alternating-current series distribution systems are being used to a very large extent. By the aid of special transformers, or regulators, any number of circuits can be run from one machine or set of bus bars, and apparatus can be built for any voltage and of any size. It is not customary, however, to build transformers of this type having a capacity greater than 100, 6.6-ampere lamps.

The constant-current transformer most in use for lighting purposes is the one manufactured by the General Electric Company nd commonly known as a "tub" transformer. Fig. 30 shows uch a transformer when removed from the case, and Fig. 29 gives a iagram of the connection of a single-coil transformer in service.

Referring to Fig. 30, the fixed coils A form the primaries hich are connected across the line; the movable coils B are the econdaries connected to he lamps. There is a re-ulsion of the coils B by he coils A when the cur-ent flows in both circuits nd this force is balanced y means of the weights t W, so that the coils B ake a position such that he normal current will ow in the secondary. On ight loads, a low voltage s sufficient, hence the sec-ndary coils are close ogether near the middle f the machine and there s a heavy magnetic leak-ge. When all of the lamps re on, the coils take the osition shown when the akage is a minimum and e voltage a maximum. Vhen first starting up, the ransformer is short-cir-uited and the secondary oils brought close to-ether. The short circuit is then removed and the coils take a osition corresponding to the load on the line.

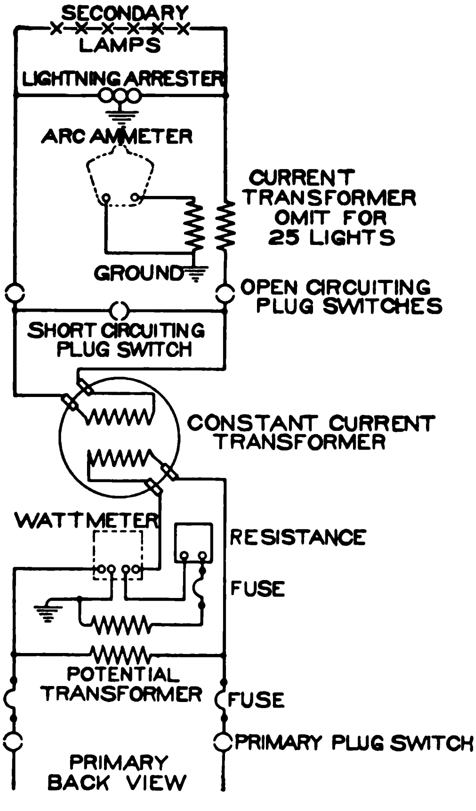


Fig. 29.

These transformers regulate from full load to $\frac{1}{3}$ rated load ithin $\frac{1}{10}$ ampere of normal current, and can be run on short ircuit for several hours without overheating. The efficiency is iven as 96% for 100-light transformers and 94.6% for 50-light ansformers at full load. The power factor of the system is from

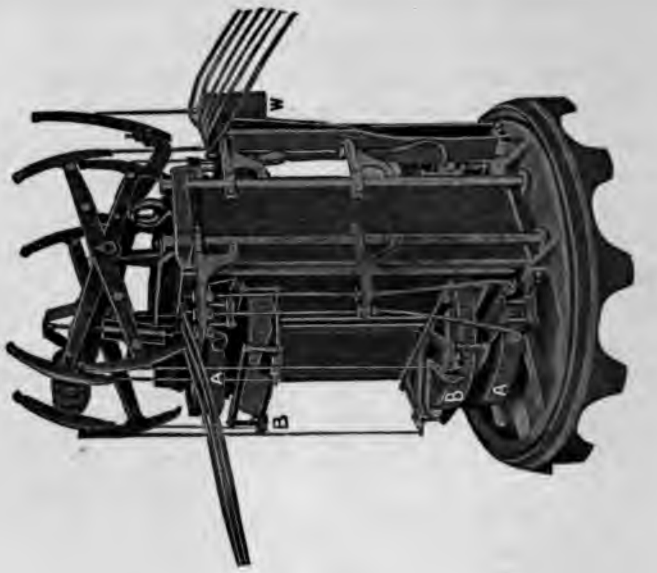
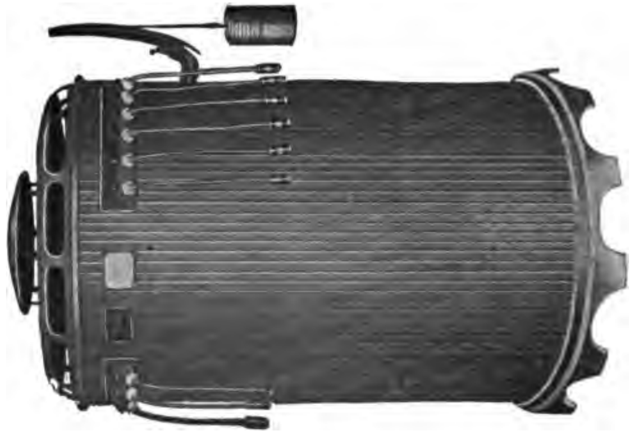


Fig. 30.



to 78% on full load, and, owing to the great amount of magnetic kage at less than full load, the effect of leakage being the ne as the effect of an inductance in the primary, the power factor greatly reduced, falling to 62% at $\frac{3}{4}$ load, 44% at $\frac{1}{2}$ load, and % at $\frac{1}{4}$ load.

Standard sizes are for capacities of 25, 35, 50, 75, and 100, 6.6 pere enclosed arcs. The low power factor of such a system on ht loads shows that a transformer should be selected of such a acity that it will be fully or nearly fully loaded at all times.

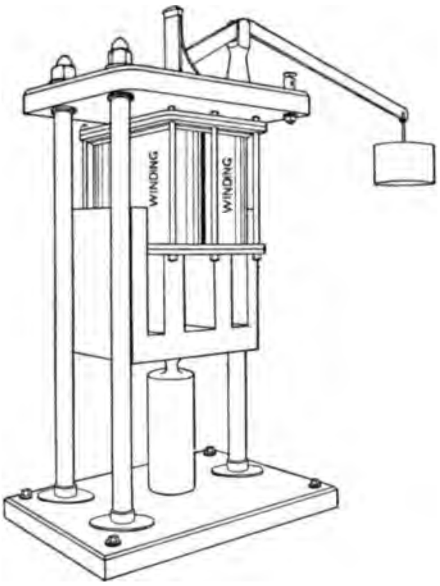


Fig. 31.

e primary winding can be istructed for any voltage l the open circuit voltages the secondaries are as fol- rs:

5	light transformer,	2300 volts.
5	" "	3200 "
0	" "	4600 "
5	" "	6900 "
0	" "	9200 "

e 50-, 75-, and 100-light nsformers are arranged for ltiple circuit operation,) circuits used in multiple, l the voltages at full load ch 4,100 for each circuit on 100-light machine.

The second system, used series distribution on ernating-current circuits, isists of a constant-potential transformer, stepping down the e voltage to that required for the total number of lamps on the tem, allowing 83 volts for each lamp, and in series with the ips is a reactive coil, the reactance of which is automatically ulated, as the load is increased or decreased, in order to keep the rent in the line constant. Fig. 31 shows such a regulator as nufactured by the General Incandescent Arc Light Company, l Fig. 32 shows this regulator connected in circuit. The in- tance is varied by the movement of the coil to include more or [illegible] in the magnetic circuit. Since the inductance in series with the lamps is high on light loads, the power factor is greatly reduced as in the constant-current transformer; and the circuits should, preferably, be run fully loaded. 60 to 65 lamps on a circuit is the maximum limit.

While used primarily for arc-light circuits, the same systems, designed for lower currents, are very readily applied to series incandescent systems.

Multiple-series and series-multiple systems combine several lamps in series and these groups in multiple, or several lamps in multiple and these groups in series, respectively. They have but a limited application.

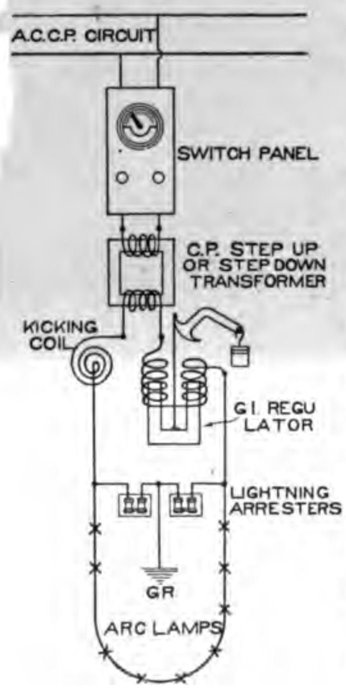


Fig. 32.

Multiple or Parallel Systems of Distribution. By far the largest number of lamps in service are connected to parallel systems of distribution. In this system, the units are connected across the lines leading to the bus bars at the station, or to the secondaries of constant-potential transformers. Fig. 33 shows a diagram of ten lamps connected in parallel. The current delivered by the machine depends directly on the number of lamps connected in service, the voltage of the system being kept constant.

Inasmuch as the flow of current in a conductor is always accompanied by a fall of potential equal to the product of the current flowing, into the resistance of the conductor, the lamps at the end of the system shown will not have as high a voltage impressed upon them as those nearer the machine. This drop in potential is the most serious obstacle that we have to overcome in multiple systems, and various schemes have been adopted to aid in this regulation. The systems may be classified as:

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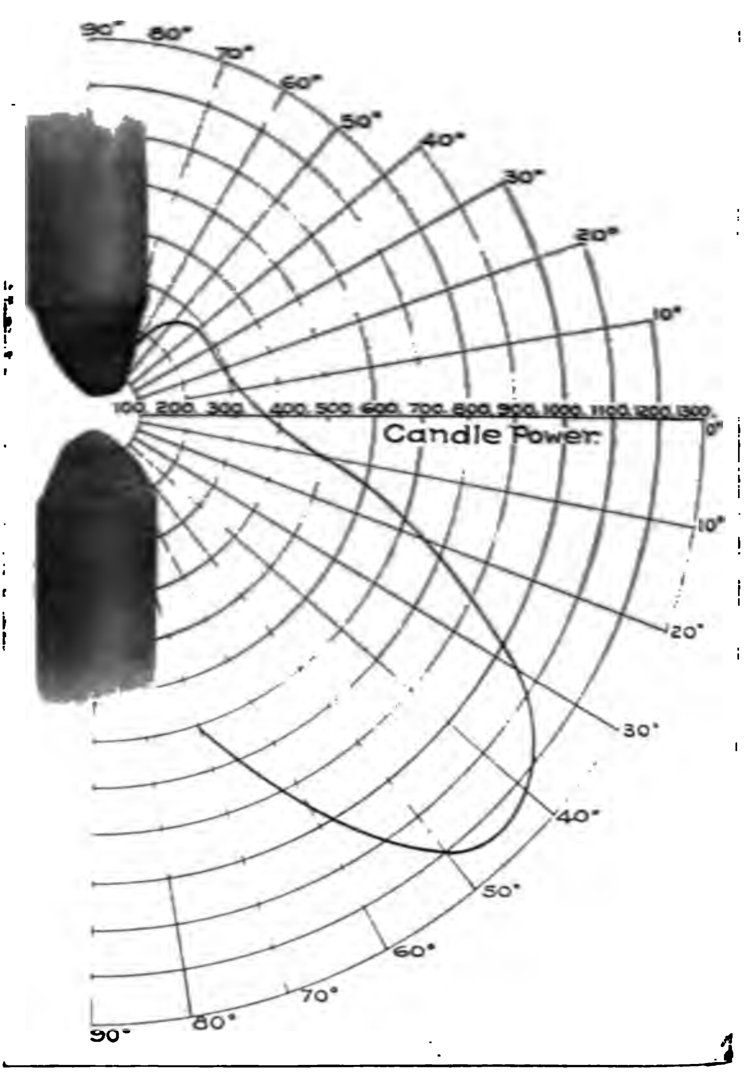
ASTOR, LENOX
TILDEN FOUNDATIONS



DISTRIBUTION CURVE FOR ARC LAMP.

Fort Wayne Electric Works.

First, Cylindrical Conductors, parallel feeding.
Second, Conical " " "
Third, Cylindrical " anti-parallel feeding.
Fourth, Conical " " "

In the cylindrical conductor, parallel-feeding system, the conductors, A, B, C, D, Fig. 33, are of the same size throughout and are fed at the same end by the generator. The voltage is a minimum at the lamps E and a maximum at the lamps F; the value of the voltage at any lamp being readily calculated.

By a conical or tapering conductor is meant a conductor whose diameter is so proportioned throughout its length that the current, divided by the cross-section or the current density, is a constant quantity. Such a conductor is approximated in practice by using smaller sizes of wire as the current in the lines becomes less.

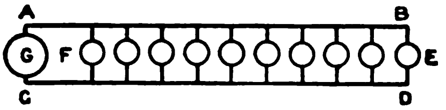


Fig. 33.

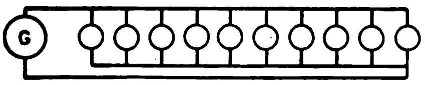


Fig. 34.

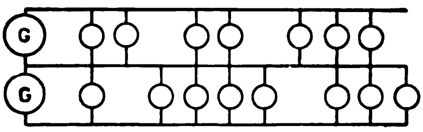


Fig. 35.

In an anti-parallel system, the current is fed to the lamps from opposite ends of the system as shown in Fig. 34.

Multiple-Wire Systems. In order to take advantage of a higher voltage for distribution of power to the lighting circuits, three- and five-wire systems have been introduced, the three-wire system being used to a very large extent. In this system, three conductors are used, the voltage from each outside conductor and the middle neutral conductor being the same as for a simple parallel system. Fig. 35 gives a diagram of this. By this system the amount of copper required for a given number of lamps is from five-sixteenths to three-eighths of the amount required for a two-wire distribution, depending on the size of the neutral conductor. The saving of copper together with the disadvantages of the system is more fully treated in the paper on Power Transmission.

ILLUMINATION.

Illumination may be defined as the quality and quantity of light which aids in the discrimination of outline and the perception of color. Not only the quantity, but the quality of the light, as well as the arrangement of the units, must be considered in a complete study of the subject of illumination.

The Unit of Illumination is the *candle-foot* and its value is the amount of light falling on a surface at a distance of one foot from a source of light one candle-power in value. The law of inverse squares, namely, that the illumination from a given source varies inversely as the square of the distance from the source, shows that the illumination at a distance of two feet from a single candle-power unit is .25 candle-foot. For further consideration of the law of inverse squares, see " Photometry ".

Illumination may be classified as *useful* illumination, when used for the ordinary purposes of furnishing light for carrying on work, taking the place of daylight, and *scenic* illumination. The latter applies to all forms of decorative lighting such as stage lighting, etc. The two divisions are not, as a rule, distinct, but the one is combined with the other.

Intrinsic Brightness. By intrinsic brightness is meant the amount of light emitted per unit surface of the light source. Table 3 gives the intrinsic brightness of several light sources.

TABLE 3.

Intrinsic Brilliancies in Candle-Power per Square Inch.

Source	Brilliancy	Notes.
Sun in zenith	600,000	Rough equivalent values, taking account of absorption.
Sun at 30 degrees elev.	500,000	
Sun on horizon	2,000	
Arc light	10,000 to 100,000	Maximum about 200,000 in crater
Calcium light	5,000	
Nernst "glower"	1,000	Unshaded.
Incandescent lamp	200-300	Depending on efficiency.
Enclosed arc	75-100	Opalescent inner globe.
Acetylene flame	75-100	
Welsbach light	20 to 25	
Kerosene light	4 to 8	Variable.
Candle	3 to 4	
Gas flame	3 to 8	Variable.
Incandescent (frosted)	2 to 5	
Opal shaded lamps, etc	0.5 to 2	

Regular Reflection. Regular reflection is the term applied to reflection of light when the reflected rays are parallel. It is of such a nature that the image of the light source is seen in the reflection. The reflection from a plane mirror is an example of this. It is useful in lighting in that the direction of light may be changed without complicating calculations aside from deductions necessary to compensate for the small amount of light absorbed.

Irregular Reflection, or diffusion, consists of reflection in which the reflected rays of light are not parallel but take various directions, thus destroying the image of the light source. Rough, unpolished surfaces give such reflection. Smooth, unpolished surfaces generally give a combination of the two kinds of reflection. Diffused reflection is very important in the study of illumination inasmuch as diffused light plays an important part in the lighting of interiors. This form of reflection is seen in many photometer screens. Light is also diffused when passing through semitransparent shades or screens.

In considering reflected light, we find that, if the surface on which the light falls is colored, the reflected light may be changed in its nature by the absorption of some of the colors. Since, as has been said, in interior lighting the reflected light forms a large part of the source of illumination, this illumination will depend upon the nature and color of the reflecting surfaces.

Whenever light is reflected from a surface, either by direct or diffused reflection, a certain amount of light is absorbed by the surface. Table 4 gives the amount of white light reflected from different materials.

TABLE 4.

Material.	
White blotting paper	.82
White cartridge paper	.80
Chrome yellow paper	.62
Orange paper	.50
Yellow wall paper	.40
Light pink paper	.36
Yellow cardboard	.30
Light blue cardboard	.25
Emerald green paper	.18
Dark brown paper	.13
Vermilion paper	.12
Blue-green paper	.12
Black paper	.05
Black cloth	.012
Black velvet	.004

From this table it is seen that the light-colored papers reflect the light well, but of the darker colors only yellow has a comparatively high coefficient of reflection. Black velvet has the lowest value, but this only holds when the material is free from dust. Rooms with dark walls require a greater amount of illuminating power, as will be seen later.

Useful illumination may be considered under the following heads:

1. Residence Lighting.
2. Lighting of Public Halls, Offices, Drafting Rooms, Shops, etc.
3. Street Lighting.

RESIDENCE LIGHTING.

Type of Lamps. The lamps used for this class of lighting are mited to the less powerful units, namely, incandescent or Nernst lamps varying in candle-power from 8 to 32 per unit. These should always be shaded so as to keep the intrinsic brightness low. The intrinsic brilliancy should seldom exceed 2 to 3 candle-power per square inch, and its reduction is usually accomplished by appropriate shading. Arc lights are so powerful as to be uneconomical for small rooms, while the color of the mercury-vapor light is an additional objection to its use.

Plan of Illumination. Lamps may be selected and so located as to give a brilliant and fairly uniform illumination in a room; but this is an uneconomical scheme, and the one more commonly employed is to furnish a uniform, though comparatively weak, ground illumination, and to reinforce this at points where it is necessary or desirable. The latter plan is satisfactory in almost all cases and the more economical of the two.

While the use of units of different power is to be recommended, where desirable, lights differing in color should not be used for lighting the same room. As an exaggerated case, the use of arc with incandescent lamps might be mentioned. The arcs being so much whiter than the incandescent lamps, the latter appear distinctly yellow when the two are viewed at the same time.

Calculation of Illumination. In determining the value of illumination, not only the candle-power of the units, but the amount of reflected light must be considered for the given location of the lamps. Following is a formula based on the coefficient of reflection of the walls of the room, which serves for preliminary calculations:

$$I = \frac{c.p. \dfrac{1}{1-k}}{d^2}$$

I = Illumination in candle-feet.
$c.p.$ = Candle-power of the unit.
k = Coefficient of reflection of the walls.
d = distance from the unit in feet.

Where several units of the same candle-power are used this formula becomes

$$I = c.p. \left(\frac{1}{d^2} + \frac{1}{d_1^2} + \frac{1}{d_2^2} + \text{---------}\right) \frac{1}{1-k}$$

or,
$$c.p. = \frac{I}{\left(\dfrac{1}{d^2} + \dfrac{1}{d_1^2} + \dfrac{1}{d_2^2} + \text{---------}\right) \dfrac{1}{1-k}}$$

where d, d_1, d_2, etc., equal the distances from the point considered to the various light sources. If the lamps are of different candle-power, the illumination may be determined by combining the illumination from each source as calculated separately. An example of calculation is given under "Arrangement of Lamps".

It is readily seen that the effect of reflected light from the ceilings is of more importance than that from the floor of a room. The value of k, in the above formula, will vary from 60% to 10%, but for rooms with a fairly light finish 50% may be taken as a good average value.

The amount of illumination will depend on the use to be made of the room. One candle-foot gives sufficient illumination for easy reading, when measured normal to the page, and probably an illumination of .5 candle-foot on a plane 3 feet from the floor forms a sufficient ground illumination. The illumination from sunlight reflected from white clouds is from 20 candle-feet up, while that due to moonlight is in the neighborhood of .03 candle-foot. It is not possible to produce artificially a light equivalent to daylight on account of the great amount of energy that would be required and the difficulty of obtaining proper diffusion.

Arrangement of Lamps. An arrangement of lamps giving a uniform illumination cannot be well applied to residences on account of the number of units required, and the inartistic effect. We are limited to chandeliers, side lights, or ceiling lights, in the majority of cases, with table or reading lamps for special illumination.

When ceiling lamps are used and the ceilings are high, some form of reflector or reflector lamp is to be recommended. In any case where the coefficient of reflection of the ceilings is less than 40%, it is more economical to use reflectors. When lamps are mounted on chandeliers, the illumination is far from uniform, being a maximum in the neighborhood of the chandelier and a minimum at the corners of the room. By combining chandeliers with side lights it is generally possible to get a satisfactory arrangement of lighting for small or medium-sized rooms.

As a check on the candle-power in lamps required, we have the following:

For brilliant illumination allow one candle-power per two square feet of floor space. In some particular cases, such as ball rooms, this may be increased to one candle-power per square foot.

For general illumination allow one candle-power for four square feet of floor space, and strengthen this illumination with the aid of special lamps as required. The location of lamps and the height of ceilings will modify these figures to some extent.

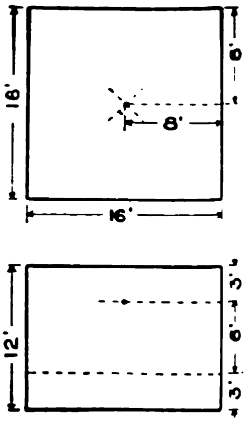


Fig. 36.

As an example of the calculation of the illumination of a room with different arrangements of the units of light, assume a room 16 feet square, 12 feet high, and with walls having a coefficient of reflection of 50%. Consider first the illumination on a plane 3 feet above the floor when lighted by a single group of lights mounted at the center of the room 3 feet below the ceiling. If a minimum value of .5 candle-foot is required at the corner of the room we have the equation

$$.5 = c.p. \frac{1}{12.8^2} \times \frac{1}{1 - .5}$$

Since $d = \sqrt{8^2 + 8^2 + 6^2} = 12.8$ (see Fig. 36)

Solving the above for the value of $c.p.$, we have

$$c.p. = \frac{.5}{\frac{1}{164} \times \frac{1}{.5}} = .5 \times 82 = 41$$

Three 16-candle-power lamps would serve this purpose very well.

Determining the illumination directly under the lamp, we have:

$$I = 48 \times \frac{1}{6^2} \times \frac{1}{1 - .5} = \frac{48}{36} \times 2 =$$

2.7 candle-feet, or five times the value of the illumination at the corners of the room.

Next consider four 8-candle-power lamps located on the side walls 8 feet above the floor as shown in Fig. 37. Calculating the illumination at the center of the room on a plane three feet above the floor, we have:

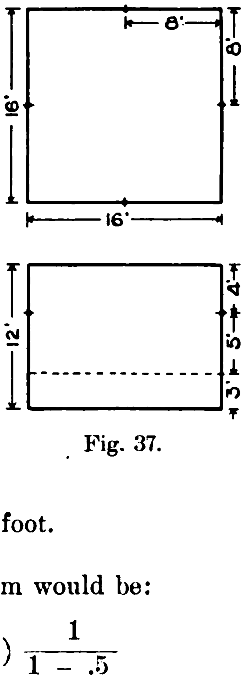


Fig. 37.

$$I = 8(\frac{1}{89} + \frac{1}{89} + \frac{1}{89} + \frac{1}{89}) \frac{1}{1 - .5}$$

$$d^2 = 8^2 + 5^2 = 64 + 25 = 89$$

$$I = 8 \times \frac{4}{89} \times 2 = .72 \text{ candle-foot.}$$

The illumination at the corner of the room would be:

$$I = 8(\frac{1}{89} + \frac{1}{89} + \frac{1}{345} + \frac{1}{345}) \frac{1}{1 - .5}$$

$$= 8(\frac{2}{89} + \frac{2}{345}) \times 2 = .45 \text{ candle-foot.}$$

In a similar manner the illumination may be calculated for any point in the room, or a series of points may be taken and curves plotted showing the distribution of the light, as well as the areas having the same illumination. Where refined calculations are desired, the distribution curve of the lamp must be used for deter-

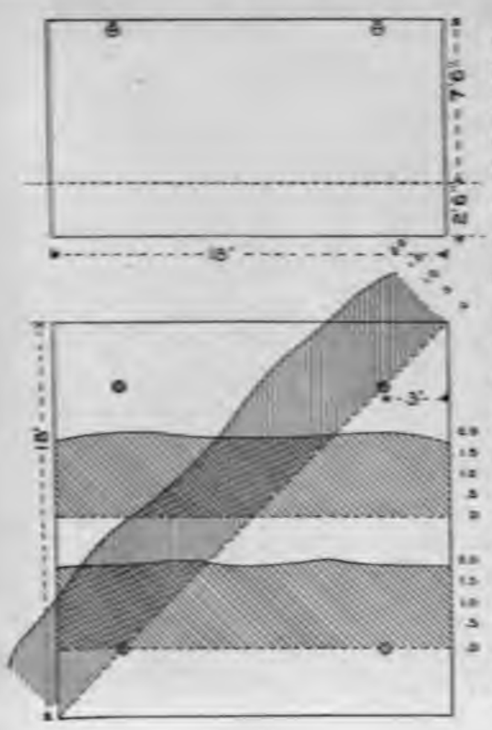


Fig. 38.

mining the candle-power in different directions. Fig. 38 shows illumination curves for the Meridian lamp manufactured by the General Electric Company. This is a form of reflector lamp made in two sizes, 25 or 50 candle-power. Fig. 39 gives the distribution curves for the 50-candle-power unit. Similar incandescent lamps are now being manufactured by other companies.

Table 5 gives desirable data in connection with the use of the Meridian lamp.

By means of the Weber, or some other form of portable photometer, curves as plotted from calculations may be readily checked after the lamps are installed. When lamps are to be permanently located, the question of illumination becomes an

TABLE 5.

Illuminating Data for Meridian Lamps.

Class Service.	Light Intensity in Candle-feet.	No. 1 Lamp (60 Watts)		No. 2 Lamp (120 Watts)		Watts per Sq. Ft. of Area Lighted With Either Lamp.
		Height of Lamp and Diameter of Uniformly Lighted Area.	Distance Between Lamps When Two or More are Used.	Height of Lamp and Diameter of Uniformly Lighted Area.	Distance Between Lamps When Two or More are Used.	
Desk or Reading Table.	3	2.9 feet.	4.9 feet.	4 feet.	7 feet.	2.50
	2	3.5 "	6 "	5 "	8.5 "	1.66
	1½	4 "	7 "	5.75 "	9.8 "	1.25
General Lighting.	1	5 "	8.5 "	7 "	12 "	0.83
	¾	5.75 "	9.8 "	8.2 "	13.9 "	0.62
	½	7 "	12 "	10 "	11 "	0.41

important one, and it is customary to determine, by calculation, the illumination curves and the isophotals, Fig. 38, as the lines showing equal illumination are called, for each room before installing the lamps. This applies to the lighting of large interiors more particularly than to residence lighting.

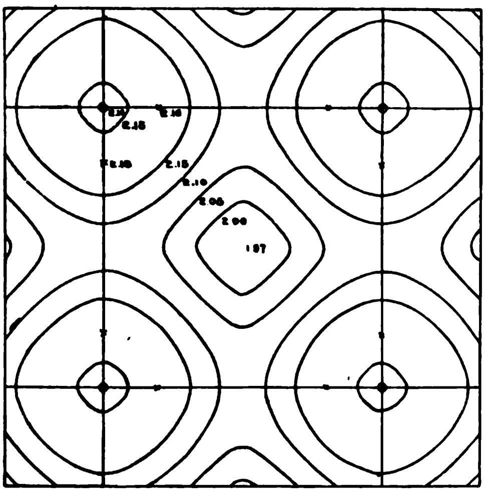


Fig. 38.

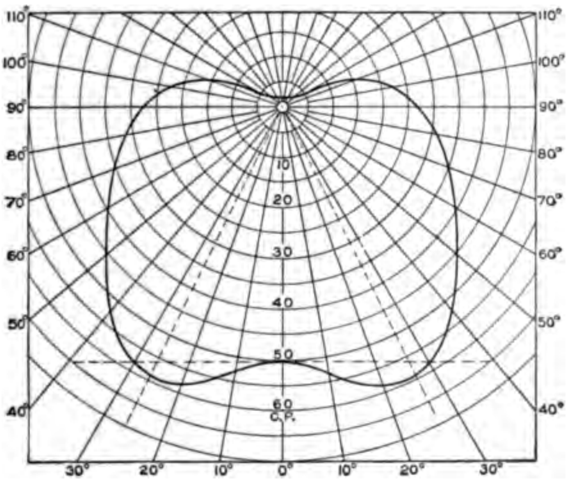


Fig. 39.

Dr. Louis Bell gives the following in connection with residence lighting:

TABLE 6.

Room.	8 c.p.	16 c.p.	32 c.p.	Sq. ft. per c.p.	Remarks.
Hall, 15′ × 20′	8			4.7	
Library, 20′ × 20′	12		1	3.1	8-c.p. reflector [lamps.
Reception room, 15′ × 15′	4			7.0	
Music room, 20′ × 25′	12		2	3.0	
Dining room, 15′ × 20′	14			2.7	8 reflect'r lamps
Billiard room, 15′ × 20′			4	2.3	32-c.p. with re- [flectors.
Porch			1		
Bedrooms (6), 15′ × 15′		14		7.0	
Dressing rooms (2), 10′ × 15′		4		4.7	
Servants' rooms (3), 10′ × 15′		3		9.4	
Bathrooms (3), 8′ × 10′		3		5.0	
Kitchen, 15′ × 15′ Pantry, 10′ × 15′		3			
Halls Cellar	10	3			
Closets (4)	4				Reflector lamps
Total	64	30	8		

LIGHTING OF PUBLIC HALLS, OFFICES, ETC.

Lighting of public halls and other large interiors differs from the illumination of residences in that there is usually less reflected light, and, again, the distance of the light sources from the plane of illumination is generally greater if an artistic arrangement of the lights is to be brought about. This in turn reduces the direct illumination. The primary object is, however, as in residence lighting, to produce a fairly uniform ground illumination and to superimpose a stronger illumination where necessary. An illlumination of .5 candle-feet for the ground illumination may be taken as a minimum.

In the lighting of large rooms it is permissible to use larger light units, such as arc lamps and high candle-power Nernst or incandescent units, while for factory lighting and drafting rooms, where the color of the light is not so essential, the Cooper Hewitt lamp is being introduced. High candle-power reflector lamps, such as the Meridian lamp, are being used to a large extent for offices and drafting rooms.

The choice of the type of lamp depends on the nature of the work. Where the light must be steady, incandescent or Nernst lamps are to be preferred to the arc or vapor lamps, though the latter are often the more efficient. When arcs are used, they must be carefully shaded so as to diffuse the light, doing away with the strong shadows due to portions of the lamp mechanism, and to reduce the intrinsic brightness. Such shading will be taken up under the heading "Shades and Reflectors". Arcs are preferable to incandescent lamps when colored objects are to be illuminated, as in stores and display windows.

In locating lamps for this class of lighting, much depends on the nature of the building and on the degree of economy to be observed. For preliminary determination of the location of groups, or the illumination when certain arrangement of the units is assumed, the principles outlined under "Residence Lighting" may be applied. It has been found that actual measurements show results approximating closely such calculated values.

When arcs are used they should be placed fairly high, twenty to twenty-five feet when used for general illumination and the ceilings are high. They should be supplied with reflectors so as to utilize the light ordinarily thrown upwards. When used for drafting-room work, they should be suspended from twelve to fifteen feet above the floor, and special care must be taken to diffuse the light.

Incandescent lamps may be arranged in groups, either as side lights or mounted on chandeliers, or they may be arranged as a frieze running around the room a few feet below the ceiling. The last named arrangement of lights is one that may be made artistic, but it is uneconomical and when used should serve for the ground illumination only. Reflector lights may be used for this style of work and the lights may be entirely concealed from view, the reflecting property of the walls being utilized for distributing the light where needed.

Ceiling lights should preferably be supplied with reflectors, especially when the ceilings are high.

Measurements taken in well-lighted rooms having a floor space of from 1,000 to 5,000 square feet show an average of 3 to 3.5 square feet per candle-power. About 2.5 square feet per candle-power should be allowed when brilliant lighting is required or the ceilings are very high, while 3.75 square feet per candle power

TABLE 7.

Lighting Data for Arc Lamps.

Place Lighted.	Clothing Store.	Weave Room.	Erecting Room.	Machine Shop.	Drafting Room.	Drafting Room.	Ship Shed.	Cataloging Dept.	Jewelry Store.
No. of sq. ft. place lighted	4000	14400	281600	42250	6275	5690	69000	4136	4000
No. lamps used	12	50	200	42	27	24	50	17	6
Circuit	A. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult.	A. C. Series.	D. C. Mult.	*D. C. Mult.	D. C. Mult.	D. C. Mult.
Cycles	60	......	......	......	60	......	......	......	......
Volts line	104	110	120	120	......	120	220	110	110
Amperes	6	3¼	6.2	6.2	7.5	4	6	4½	5
Volts at arc	72	75	80	80	72	80	80	80	80
Power factor of lamp	.69	......	......	......	.86	......	......	......	......
Watts per lamp	430	357	744	744	490	480	660	495	550
Watts per sq. ft. (term.)	1.29	1.24	.53	.74	2.11	2.02	.478	2.03	.825
Kw. at term. (whole installation)	5.16	17.8	148.8	31.25	13.22	11.52	33	8.42	3.3
Kw. at arc (whole installation)	4.62	12.28	99.2	20.8	12.42	7.68	24	6.12	2.4
Sq. ft. lighted per lamp	333	288	1408	1006	232	237	1380	243	667
Sq. ft. lighted per amp.	55.6	88.6	227	162	31	59.2	230	54.1	133.5
Enclosing globe	Opal		Opal.	Opal.	Opal.	Opal.		Opal.	Opal.
Height and style of ceiling	12′ white steel.	Saw Toothed.	Trussed.	Trussed.	12′ White.	Trussed.	160′ Trussed.	13′ 9″ Maroon.	16′ 10′ White.
Reflector system used	Concentric Diffuser.	Adjust. Diffuser.	9″ Mirror.	9″ Mirror.	Concentric Diffuser.	16 Adj. Dif. 8 Con. Dif.	12″ Mirror.	Concentric Diffuser.	Concentric Diffuser.
Height of arc from floor	9′ 6″	12′ to 15′	46′	47′	9′	15′	150′	10′ 7″	13′ 2″
Distance between lamps	14′ to 18′	24′	32′ to 38′	30′ 9″	15′	12′ to 25′	17′ to 20′	14′ to 18′	16′ to 25′

will give good illumination when lights are well distributed and there is considerable reflected light.

In factory and drafting room lighting, the lamps must be arranged to give a strong light where most needed, and located to prevent such shadows as would interfere with the work.

Following are tables showing the number and distribution of arc and mercury-vapor lamps for lighting large rooms. Table 7 refers to arc lights as actually installed.

TABLE 8.

Lighting Data for Cooper-Hewitt Lamps.

Drafting Room.	2,140 sq. ft.	8 V-5 lamps.
	265 sq. ft. per lamp.	8 × 3.3 amperes = 26.5 amp.
	voltage 110.	80 sq. ft. per amp.
Office.	1,100 sq. ft.	3 H-4 lamps.
	366 sq. ft. per lamp.	3x3.3 amp. = 10 amp.
	voltage 110.	110 sq. ft. per amp.
Factory.	12,000 sq. ft.	30 V-4 lamps.
	400 sq. ft. per lamp.	30x1.7 amp. = 51 amp.
	voltage 110.	

STREET LIGHTING.

In studying the lighting of streets and parks, we find that, except in special cases, such as narrow streets and high buildings, there is no reflected light which aids the illumination aside from that due to special shades or reflectors on the lamp itself. Such reflectors are necessary if the light ordinarily thrown above the horizontal plane is to be utilized.

In calculating the illumination due to any type of lamp at a given point it is necessary to know the distribution curve of the lamp used and the distance to the point illuminated. The approximate illumination is given by the formula,

$$I = \frac{c.p.}{h^2 + d^2}$$

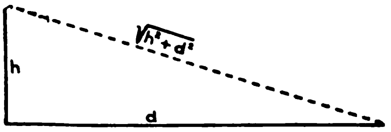


Fig. 40.

when I = illumination in candle-feet.

c.p. = candle-power of the unit, determined from the distribution curve of the lamp.

h = distance the lamp is mounted above the ground, in feet, and d = distance from the base of the pole supporting the lamp to the point where the illumination is being considered. See Fig. 40.

While this will give the illumination in candle-feet, the nature of the lighting cannot be decided from this alone, but the total amount of light must also be considered. Thus, a street lighted with powerful units and giving a minimum illumination of .05 candle-foot would be considered better illuminated than one having smaller units so distributed as to give the same minimum value.

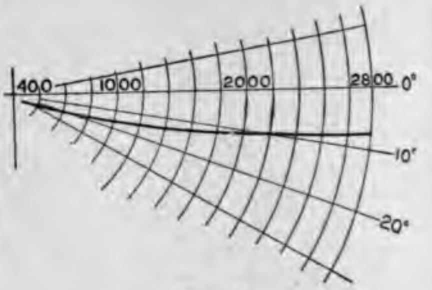


Fig. 41.

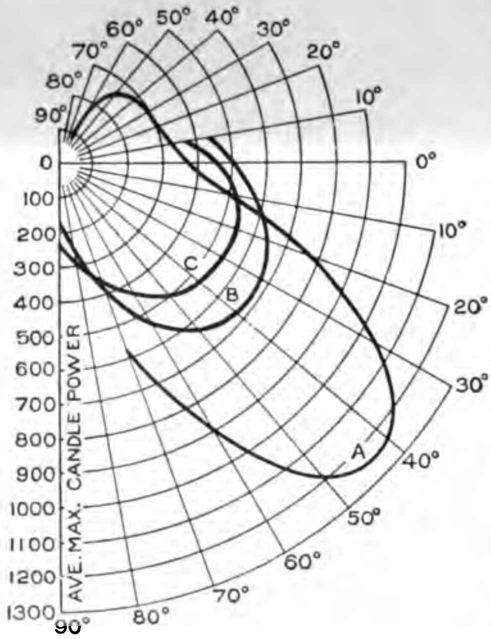


Fig. 42.

Since a uniform distribution of light is desirable, for economic reasons, the ideal distribution curve of a lamp for street lighting would be a curve which shows a low value of candle-power thrown directly downward, but with the candle-power increasing as we approach the horizontal. Such an ideal distribution curve is shown in Fig. 41.

Actual distribution curves taken from commercial arc lamps are given in Fig. 42, in which

Curve A shows distribution curve for a 9.6-ampere, open, direct-current arc.

Curve B shows distribution curve for a 6.6 ampere, D.C. enclosed arc.

Curve C shows distribution curve for a 7.5-ampere, A.C. enclosed arc.
Globes used with B and C are opal, inner globes, clear, outer globes.
Globes used with A are clear outer globes.
A street reflector was used with the enclosed arcs.

A series of curves known as illumination curves may be readily calculated showing the illumination in candle-feet at given distance from the foot of the pole supporting the lamp. Illumination curves corresponding to the distribution curves in Fig. 42 are given in Fig. 43 where A′, B′, and C′ correspond to A, B, and

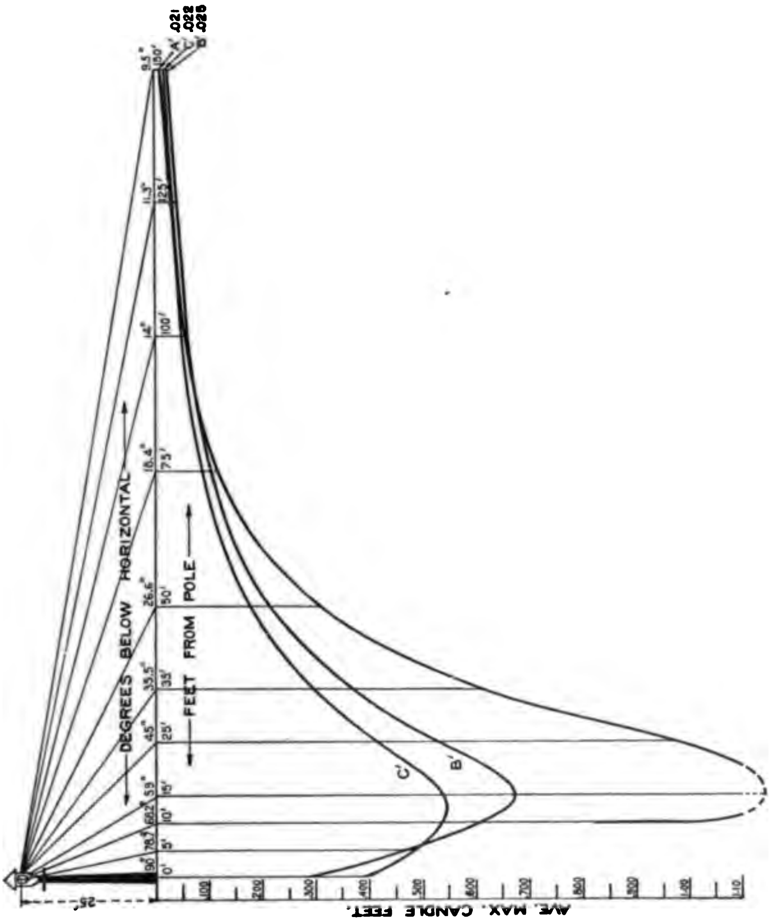


Fig. 43.

C in Fig. 42. These curves correspond to actual readings taken with commercial lamps. Similar curves for incandescent lamps are shown in Fig. 44. A value of .03 candle-foot is about the minimum for good street lighting. Open arcs should be placed at least 25 feet above the ground; 30 to 40 feet is better, especially if the space to be illuminated is quite open. With enclosed arcs it is often advantageous to place them as low as 18 to 20 feet from the ground. Table 9 gives the distance between lights for different types of arcs for good illumination.

TABLE 9.

Kind of Light.	Distance between Lights.	Lights Per Mile.
6.6-ampere enclosed D.C. arc............	340 Feet.	15
9.6-ampere open D.C. arc................	315 "	17
6.6-ampere enclosed A.C. arc............	275 "	19
6.6-ampere open D.C. arc................	260 "	20

In considering the type of arc light to be used we must turn to the illumination curves as shown in Fig. 43. These curves show that the illumination from a direct-current open arc in its present form is superior to that from a direct-current enclosed arc, taking the same amount of power, in the vicinity of the pole, but at a distance of 100 feet, the illumination from the enclosed arc is better. This illumination is still more effective on account of the absence of such strong light as is given by the open arc near the pole. The pupil of the eye adjusts itself to correspond to the brightest light in the field of vision, and we are unable to see as well in the dimly-lighted section as when the maximum intensity is less. The characteristics of the open, direct-current arc lamps are as follows:

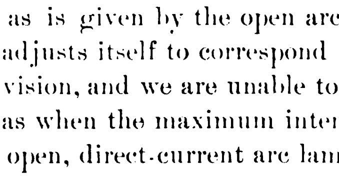


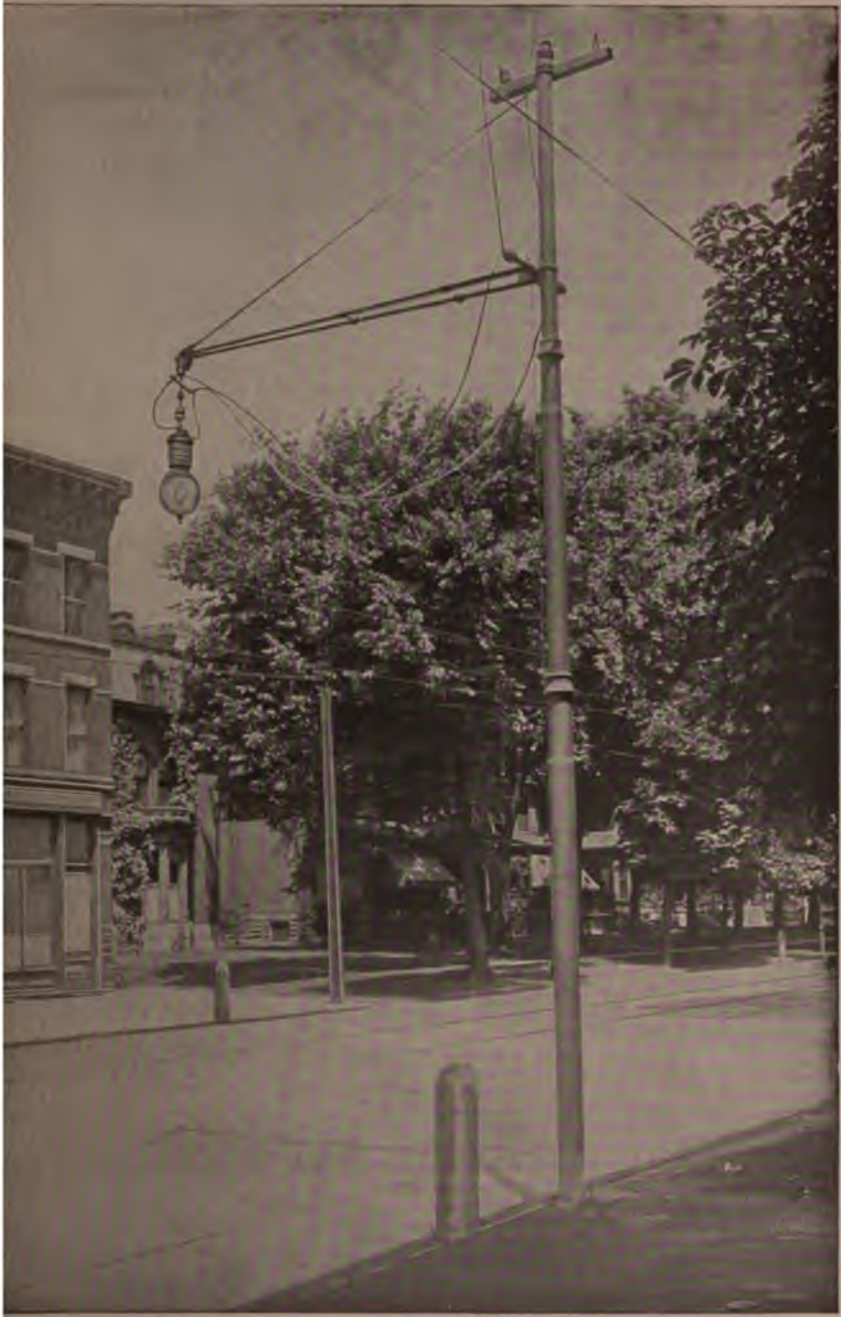
Fig. 44.

The mean spherical candle-power and energy required at the arc are variable.

Fluctuations of light are marked, due to wandering of the arc, flickering due to the wind and lack of uniformity of the carbons.

Dense shadows are cast by the side rods and the lower carbon, while the light is objectionably strong in the vicinity of the pole.

With the enclosed arc the mean spherical candle-power and the watts consumed at the arc are fairly constant.



MAST SUSPENSION OF ARC LAMPS.
General Electric Company.

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ASTOR, LENOX
TILDEN FOUNDATIONS

No shadows are cast by the lamps, and the illumination is not subject to such wide variations. The enclosed arc is much superior to the open arc using the same amount of energy. This applies to the open arc as it is now used. With proper reflection and diffusion of the light such as might be accomplished by extensive or special shading, we ought to be able to get as good distribution from the open arc with a greater total amount of illumination.

In comparing the direct-current with the alternating-current enclosed arc, we see that the direct-current arc gives slightly more light than the alternating lamp, but this may be more than counterbalanced by the better distribution of light from the alternating-current lamp. The selection of A.C. or D.C. enclosed lamps will usually depend on other conditions, such as method of distribution of power, efficiency of plant, etc.

Series incandescent lamps are used considerably for lighting the streets in residence sections of cities or where shade trees make it impracticable to use arcs. These vary in candle-power from 16 to 50 or even higher, and are usually constructed so as to take from two to four amperes. The best arrangement of these is to mount them on brackets a few feet from the curb, with alternate lamps on opposite sides of the street. The distance between the lamps depends on their power. 50 candle-power lamps spaced 100 feet between lamps, give a minimum illumination of .02 candle-foot. 25 candle-power lamps spaced 75 feet between lamps will serve where economy is necessary.

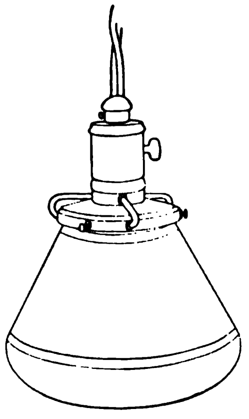

Fig. 45.

SHADES AND REFLECTORS.

Lamps, as ordinarily constructed, do not always give a suitable distribution of light, while the intrinsic brightness is often too high for interior lighting. Shades are intended to modify the intensity of the light, while reflectors are used for the purpose of changing its direction. Frequently the two are combined in various ways. Shades are also used for decorative purposes, but, if possible, these should be of such a nature as to aid illumination rather than to reduce its efficiency.

A considerable amount of light is absorbed by the material used for the construction of shades. Table 10 shows the approximate amount absorbed by some materials.

Of the great number of styles of shades and reflectors in use, only a few of the more important will be considered here.

TABLE 10.

	Per Cent
Clear glass	10
Alabaster glass	15
Opaline glass	20-40
Ground glass	25-30
Opal glass	25-60
Milky glass	30-60
Ground glass	24.4
Prismatic glass	20.7
Opal glass	32.2
Opaline glass	23.0

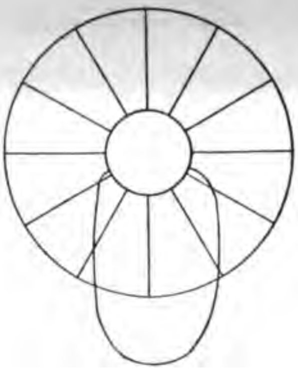

Fig. 46.

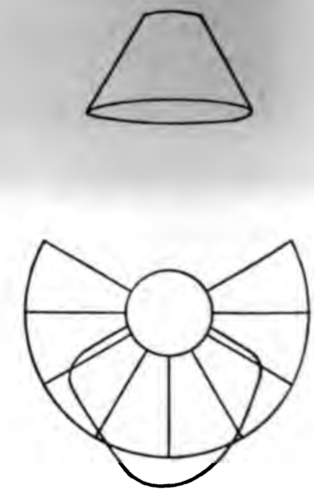

Fig. 47.

One of the simplest methods of shading incandescent lamps is by the use of "frosted" globes. These serve to reduce the intrinsic brightness of the lamp, and should be freely used for residence lighting when separate shades are not installed. Frosted globes are also used in connection with reflectors for the purpose of diffusing the reflected light. The McCreary shade as shown in

Fig. 45 is an example of such a combined shade and reflector. Fig. 46 shows the distribution curve taken from an incandescent lamp using a McCreary shade. Fig. 47 shows the distribution of light from a conical shade. Fig. 39 shows the distribution of light brought about by means of a spiral filament and a reflector as used in the Meridian lamp.

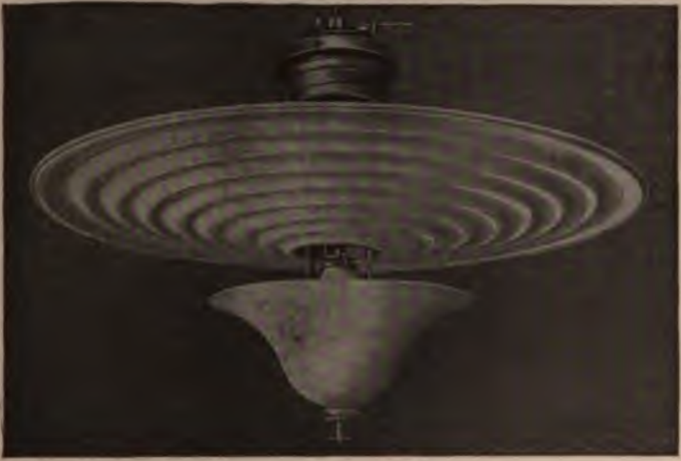

Fig. 48.

Holophane globes are made for both reflecting and diffusing the light, and they can be made to bring about almost any desired distribution with but a small amount of absorption of light. These consist of shades of clear glass having horizontal grooves forming surfaces which change the direction of light by refraction or total reflection as is necessary. The diffusion of light is effected by means of deep, rounded, vertical grooves on the interior surface of the globe. While these globes are of clear glass and absorb an amount of light corresponding to clear glass, the light is so well diffused that the filament of the lamp cannot be seen, and the globe appears as if made of some semi-transparent material. The objections to globes of this type are their high cost and the difficulty in keeping them clean.

Fig. 48 shows an enclosed arc lamp fitted with a shade and a concentric "diffuser". This shade is applied to an inverted arc, which is a direct-current arc in which the lower carbon is made positive. The effect of this combination is best shown in Fig. 49. Fig. 50 shows the change in the illumination curve produced by such shading. Inverted arcs have a considerable application when the light may be readily reflected and diffused as in lighting large rooms with light finish.

Fig. 51 shows another form of adjustable diffuser which finds application when a soft light is required for a definite direction. This shade is very readily adapted to shop lighting.

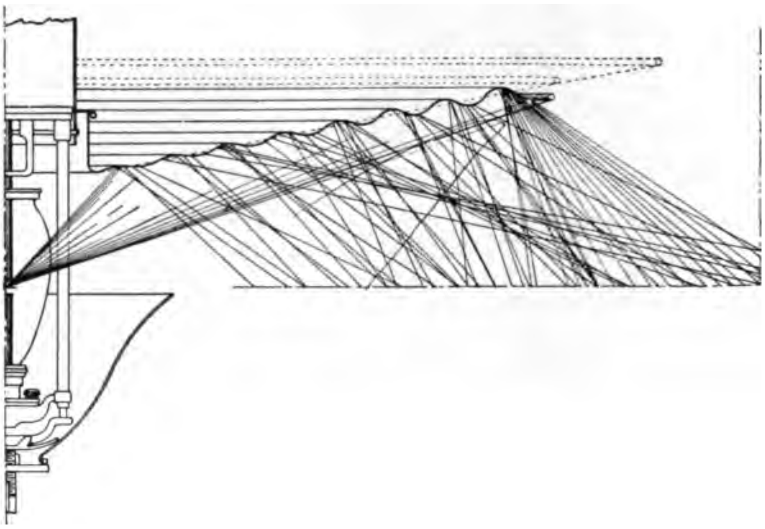

Fig. 49.

The use of opal enclosing globes is recommended for arc lamps used for street lighting for the reason that they change the distribution of the light so that it covers a greater area, and the light is so diffused as to obliterate shadows in the vicinity of the lamp. Table 11 gives the efficiency of different globe combinations for street lighting assuming the opal inner and the clear outer globes as 100%.

TABLE 11.

Opal enclosing and clear outer	100 per cent.
Clear " " clear "	91.2 "
" " " opal "	85.1 "
Opal " " opal "	82.7 "

PHOTOMETRY.

Photometry is the art of comparing the illuminating properties of light sources, and forms one branch of scientific measurement. Its use in electric illumination is to determine the relative values of different types of lamps as sources of illumination, together with their efficiency; also by means of the principles of photometry, we are able to study the distribution of illumination for any given arrangement of light sources.

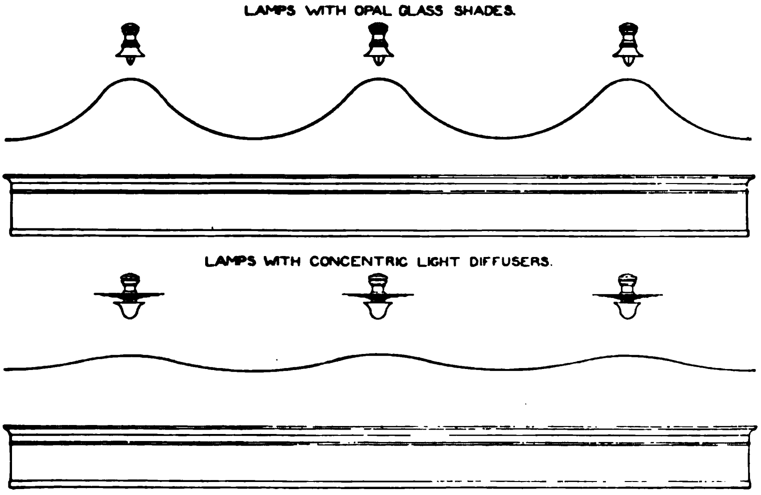
LAMPS WITH OPAL GLASS SHADES.
LAMPS WITH CONCENTRIC LIGHT DIFFUSERS.

Fig. 50.

Light Standards. Inasmuch as sources of light are compared with one another in photometry, we must have some standard, or unit, to which all light sources are reduced. This unit is usually the candle-power and the rating of most lamps is given in candle-power.

While the candle-power remains the unit and is based on the standard English candle, other light standards have been introduced and are much more desirable.

The English Candle. The English candle is made of spermaceti extracted from crude sperm oil, with the addition of a small quantity of beeswax to reduce the brittleness. Its length is ten inches, and its diameter .9 inch at the bottom and .8 inch at the top, and its weight is one-sixth of a pound. Great care is taken in the preparation of the wick and spermaceti. This candle burns with a normal height of flame of 45 millimeters and consumes 120 grains per hour when burning in dry air at normal atmospheric pressure. Under these conditions, the light given by a single candle is one candle-power.

When used for measurements, the candle should be allowed to burn at least fifteen minutes before taking any readings. At the end of this period the wick should be trimmed, if necessary, and when the flame height reaches 45 millimeters, readings can be taken. The candle should not require trimming when the proper height of flame has been reached. It is best to weigh the amount of material consumed by balancing the candle on a properly arranged balance when the first reading is taken, and again balancing at the end of a suitable period—ten to fifteen minutes. The candle-power of the unit is then, practically, directly proportional to the amount of the material consumed.

Fig. 51.

The objections to the candle as a unit are that it burns with an open flame which is subject to variation in height and to the effect of air currents. The color of the light is not satisfactory, being too rich in the red rays and the composition of the spermaceti is more or less uncertain.

The German Candle is made of paraffine, very pure, and burns with a normal flame height of 50 millimeters and is subject to the same disadvantages as the English candle. It may be necessary to trim the wick to keep the flame height at 50 millimeters. The light given is a trifle greater than for the spermaceti candle.

The Carcel Lamp is built according to very careful specifications and burns colza (rape seed) oil. It has been used to a large extent in France, but its present application is limited.

The Pentane Lamp is a specially constructed lamp burning pentane, prepared by the distillation of gasoline between narrow limits of temperature. This standard is not extensively used.

The Amyl Acetate Lamp. This lamp, known also as the Hefner lamp, is at present the most desirable standard. It is a lamp built to very careful specifications, especially with regard to the dimension of the wick tube. It burns pure amyl acetate and the flame height should be 40 millimeters. This flame height must be very carefully adjusted by means of gauges furnished with the lamp. Amyl acetate is a colorless hydrocarbon prepared from the distillation of amyl alcohol obtained from fusil oil, with a mixture of acetic and sulphuric acids, or by distillation of a mixture of amyl acetate, sulphuric acid, and potassium acetate. It has a definite composition, and must be pure for this use.

The most serious disadvantage of this standard is the color of the light, inasmuch as it has a decidedly red tinge and is not readily compared with whiter lights. Its value is affected somewhat by the moisture in the air and the atmospheric pressure, but it excels all other standards in that it is quite readily reproduced.

Below is given the accepted value of the English and German candle in terms of the Hefner unit.

The Paraffine Candle (Vereinskerze) at a flame height of 50 millimeters. = 1.2 Hefner Units.

The English candle at a flame height of 45 millimeters.... = 1.14 Hefner Units.

Working Standards. The units just described, together with some others, form reference standards, but an incandescent lamp is generally used as the working standard in all photometers. An incande lamp, when used for this work, should be burned for about two hundred hours, or until it has reached the point in the life curve where its value is constant, and it should then be checked by means of some standard when in a given position and at a fixed voltage. It then serves as an admirable working standard if the applied voltage is carefully regulated. Two such lamps should always be used—the one to serve as a check on the other; the checking lamp to be used for very short intervals only.

Photometers. Two light sources are compared by means of a photometer which, in one of its simplest forms, consists of what is known as a Bunsen screen mounted on a carriage between the two lights being compared, with its plane at right angles to a line passing through the light sources, and arranged with mirrors or prisms so that both sides of the screen may be observed at once. The Bunsen screen consists of a disc of paper with a portion of either the center, or a section around the center, treated with paraffine so as to render it translucent. If the light falling on one side of this screen is in excess, the translucent spot will appear dark on that side of the screen and light on the opposite side. Care must be taken to see that the two sides of the screen are exactly alike, otherwise there will be an error introduced in using the screens. It is well to reverse the screen and check readings whenever a new lot of lamps are to be tested. When the light falling on the two sides of the screen is the same, the transparent spot disappears. The values of the two light sources are then directly proportional to the square of their distances from the screen. As an example, consider a 16 candle-power lamp being compared with a standard candle. Say the translucent spot disappears when the screen is distant 60 centimeters from the standard candle, we then have the proportion,

$$x : 1 = (240)^2 : (60)^2 = 16 : 1,$$

showing that the lamp gives 16 candle-power.

The above law is known as the law of inverse squares, and holds true only when the dimensions of the light sources are small compared with the distance between them, and when there are no reflecting surfaces present as when the readings are taken in a dark room.

The proof that the light varies inversely with the square of distance from the source is as follows:

Consider two spherical surfaces, Fig. 52, illuminated by a source of light at the center. The same quantity of light falls on both surfaces.

Area of S $= 4\pi R^2$ sq. ft. (R is in feet.)

Area of $S_1 = 4\pi R^2_1$ sq. ft.

Let Q = total quantity of light and q = light falling on unit surface. Then,

$$q = \frac{Q}{4\pi R^2}$$

$$q_1 = \frac{Q}{4\pi R^2_1}$$

$$q : q_1 = \frac{Q}{4\pi R^2} : \frac{Q}{4\pi R^2_1}$$

$$= 4\pi R^2_1 : 4\pi R^2$$

$$\frac{q}{q_1} = \frac{R^2_1}{R^2}$$

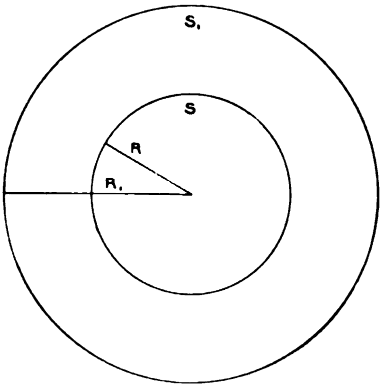

Fig. 52.

Fig. 53 shows the relation in another way. The area of C, distant two units from the source of light A, is four times that of B which is distant one unit.

The Lummer-Brodhun Photometer. In addition to the Bunsen Screen described, there are several other forms of photometers, the most important of which is the Lummer-Brodhun. The essential feature of this instrument is the optical train which serves to bring into contrast the portions of the screen illuminated by the two sources of light. Referring to Fig. 54, the screen S is an opaque

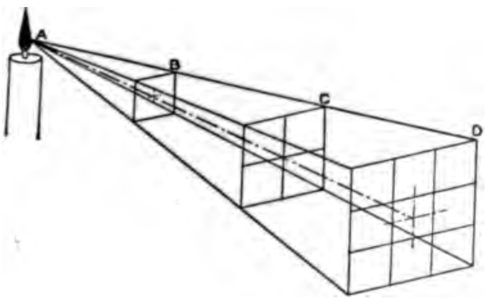

Fig. 53.

screen which reflects the light falling upon it from L, to the mirror M, when it is again reflected to the pair of glass prisms A, B. The surfaces *sr* are ground to fit perfectly and any light falling on this surface will pass through the prisms. Light falling on the surface *ar* or *bs* will be reflected as shown by the arrows. We see then that the light from L, which falls on *ar* and *bs*, is reflected to the eye piece or telescope T, while that falling on *sr* is transmitted to and absorbed by the black interior of the containing box. Likewise, the light from the screen L_1 is reflected by the screen M_1 to the pair of prisms A, B. The rays falling on the surface *sr* pass through to the telescope T, while the rays falling on *ar* and *bs* are reflected and absorbed by the black lining of the case. The field of light, as then viewed through the telescope, appears as a disc of light produced by the screen L_1, surrounded by an annular ring of light produced by L. When the illumination on the two sides of the screen is the same, the disc and ring appear alike and the dividing circle disappears.

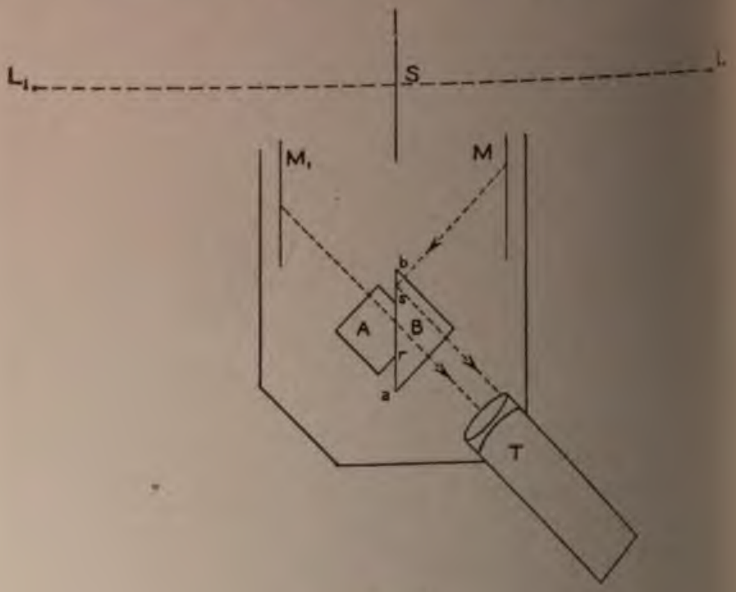

Fig. 54.

In using this screen, it is mounted the same as the Bunsen screen and readings are taken in the same manner. The screen and prisms are arranged so that they can be reversed readily and two readings should always be taken to compensate for any inequalities in the sides of the screen and the reflecting surfaces, a mean of the two readings serving as the true reading. This form of screen is used when especially accurate comparisons are required.

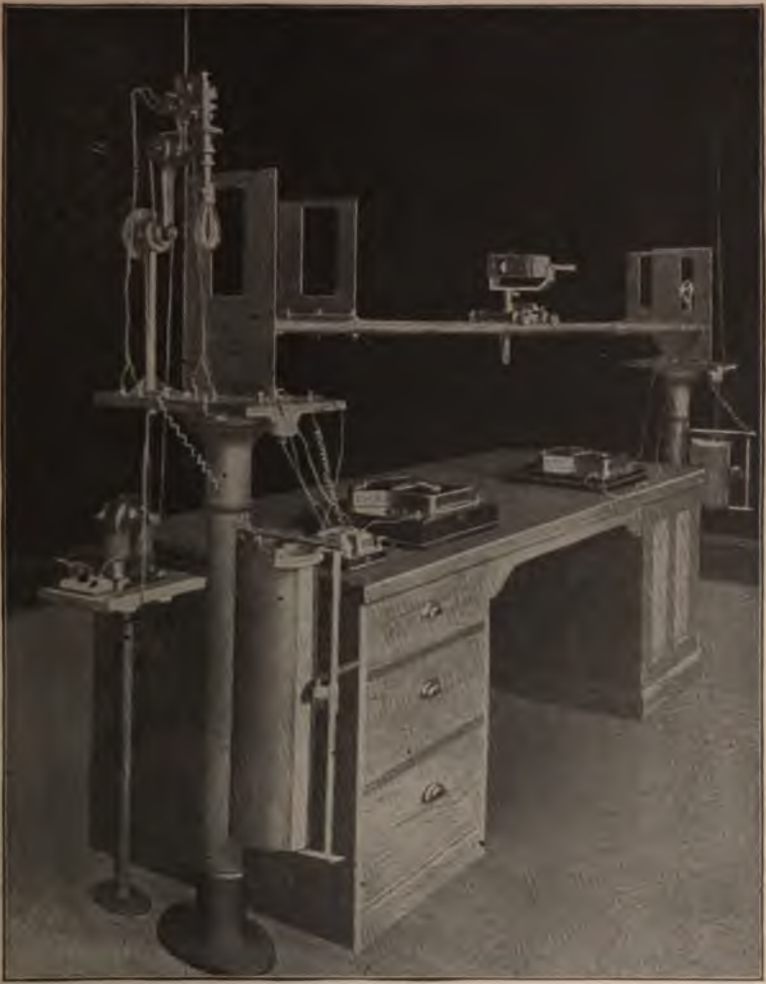

Fig. 55.

Fig. 55 shows a complete photometer with a Lummer-Brodhun screen, while Fig. 56 shows a Bunsen Screen and sight box.

In Fig. 55, the lamps are shaded by means of curtains so as to leave only a small opening toward the screen.

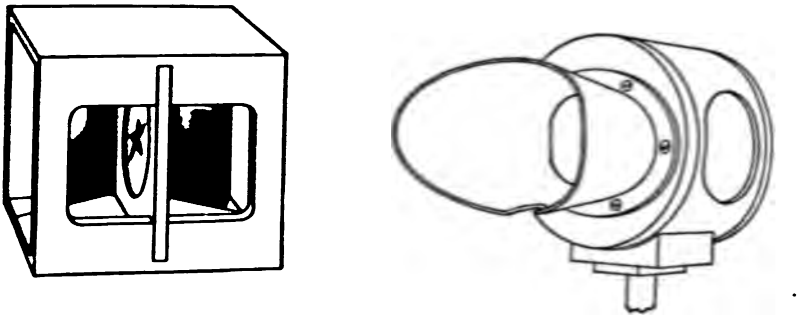

Fig. 56.

The Weber Photometer. As an example of a portable type of photometer, we have the Weber. This photometer, shown in Fig. 57, is very compact and is especially adapted to measuring intensity of illumination as well as the value of light sources; it may be used for exploring the illumination of rooms or the lighting of streets.

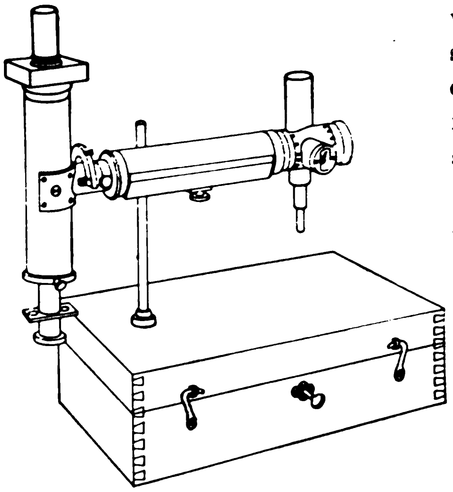

Fig. 57.

This apparatus consists of a tube A, Fig. 58, which is mounted horizontally and contains a circular, opal glass plate *f*, which is movable by means of a rack and pinion. To this screen is attached an index finger which moves over a scale attached to the outside of the tube. A lamp L, burning benzine, is mounted at the end of this tube. The benzine used should be as pure as possible, and the flame height should be carefully adjusted to 20 mm. when taking readings. At right angles to the tube A is mounted the tube B which contains an eye piece at O, a Lummer-Brodhun contrast prism at *p* and a support for opal or colored glass plates at *q*.

Operation. The tube B is turned toward the source of light to be measured, the distance from the light to the screen at *q* being noted. The light from this source is diffused by the screen at *q*, while that from the standard is diffused by the screen *f*. By moving the screen *f*, the light falling on either side of the prism *p* can be equalized. The value of the unknown source can be determined from the reading of the screen *f*, the photometer having previously been calibrated by means of a standard lamp in place of the one to be measured. The calibration may be plotted in the form of a curve or it may be denoted by a constant, C, when we have the formula,

$$I' = C \frac{L^2}{l^2}$$

C corresponds to a particular plate at *q*,

l = distance of screen *f* from the benzine lamp, and L = distance from the screen *q* to the light source being measured. Screens of different densities may be used at *q*, depending on the strength of the light source.

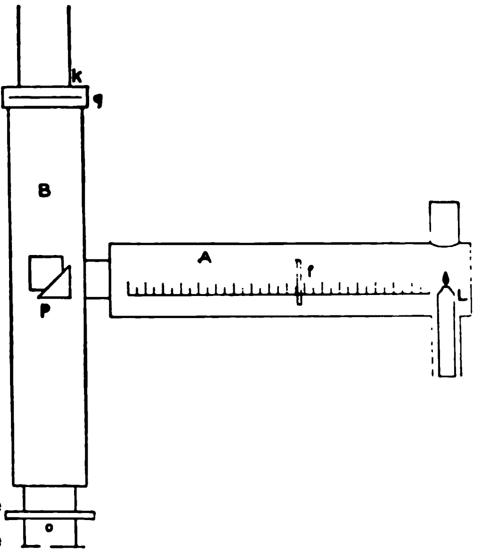

Fig. 58.

When used for measuring illumination, a white screen is used in connection with this photometer. The screen is mounted in front of the opening at *q*, and turned so that it is illuminated by the source being considered. Readings of the screen *f* are taken as before. A calibration curve is plotted for the instrument, using a known light source at known distance from the white screen when the instrument is mounted in a dark room.

A photometer, known as the **Matthews' Integrating Photometer,** has recently been placed on the market, and a very good idea

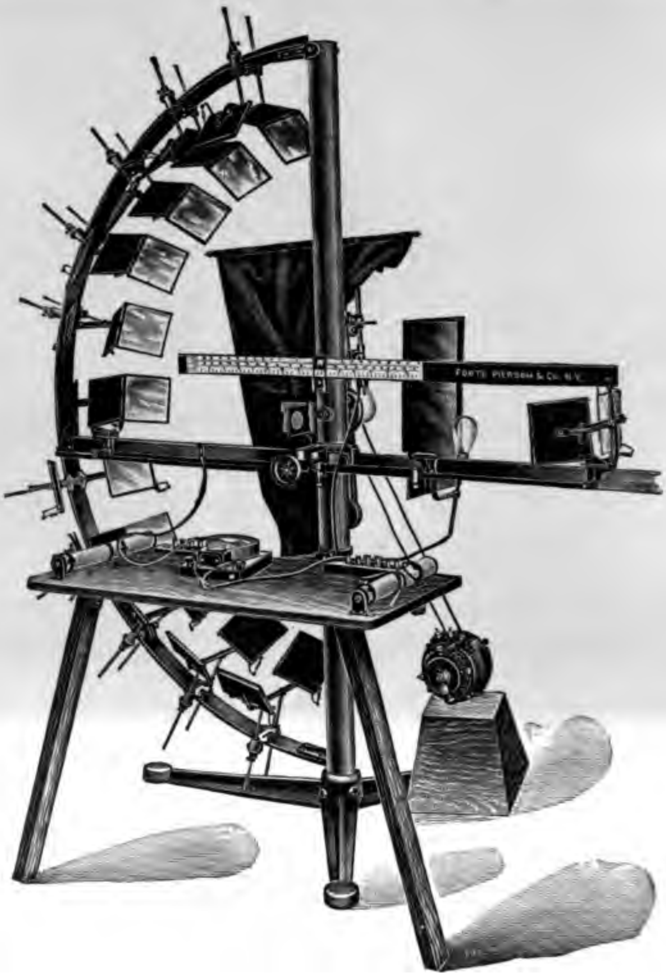
FORTE PIERSON & CO. N.Y.

Fig. 59.

of its construction can be obtained from Fig. 59. By means of a system of mirrors, the light given by the lamp in several directions may be integrated and thrown on the photometer screen for comparison with the standard, the result giving the mean spherical candle-power from one reading. By covering all but one pair of screens, the light given in any one direction is easily determined.

Incandescent Lamp Photometry. *Apparatus.* Some sort of screen, either the Bunsen type or the Lummer-Brodhun screen preferred, should be mounted on a carriage moving on a suitable scale, and the lamp holders, one for the standard, the other for the lamp to be tested, are mounted at the ends of this scale. There are several types of so-called station photometers arranged so as to be very convenient for testing incandescent lamps. Fig. 60 shows one form of station photometer manufactured by Queen & Co. The controlling rheostats and shielding curtains are not shown here. Fig. 61 shows a form of portable photometer for incandescent lamps. The length of scale should not be less than 100 centimeters, and 150 to 200 centimeters is preferred. This scale may be divided into centimeters or, for the purpose of doing away with much of the calculation, the scale may be a *proportional scale*. This scale is based on the law of inverse squares and reads the ratio of the squares of the distances from the two lights being compared. If the standard used always has the same value, the scale may be made to read in candle-powers directly.

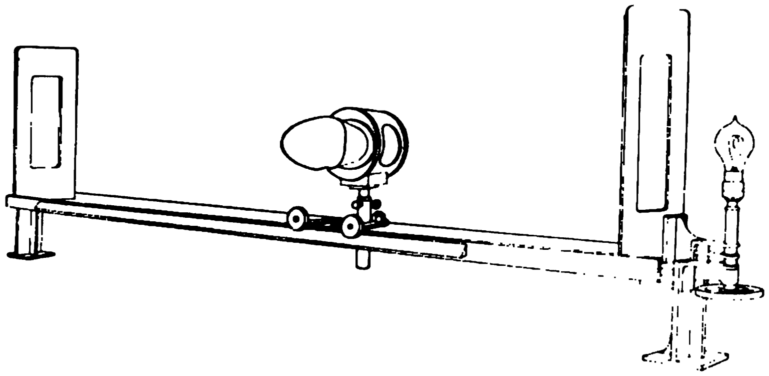

Fig. 60.

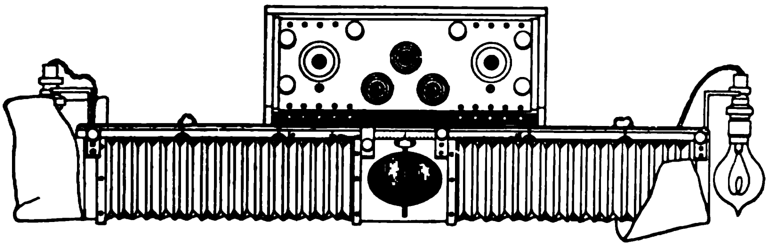

Fig. 61.

For mean horizontal candle-power measurements, the lamp should be rotated at 180 revolutions per minute, when mounted in a vertical position.

For distribution curves a universal lamp holder which will allow the lamp to be placed in any position, and which indicates this position, is used.

For mean spherical candle-power, the following method is used when the Matthews photometer is not available:

The lamp is placed in an adjustable holder and readings taken with the lamp in thirty-eight positions, as follows:

The measurement of the spherical intensity. For convenience the tip of the lamp and its base may be termed the north and south poles respectively.

“The mean of 13 readings taken at intervals of 30°, is taken to give the mean horizontal candle-power.

Beginning again at 0° azimuth, thirteen readings are made in the prime meridian or vertical circle, the interval again being 30°, and the last reading checking the first.

It will be noticed that four readings, two being check readings, have been made at 0° azimuth in each case. The mean of the four is taken as the *standard reading*, it being the value of the intensity, in this position, should the lamp be used as a standard.

Additional sets of thirteen readings each—the last reading checking the first one—are similarly made on each of the vertical circles through 45°, 90°, and 135° azimuth.

In combining the readings for the mean spherical intensity, a note is taken of the repetitions.

Neglecting the repetitions, which may also be omitted in part, in the practice of the method, there remain thirty-eight points, as follows:

	Distributed Values.
The mean of four measurements at the north pole of the lamp......	1
Four measurements on each of the vertical circles through 0° and 90° azimuth at vertical circle readings of 60°, 120°, 240°, and 300°.	8
Four measurements on each of the vertical circles through 0°, 45°, 90°, and 135° azimuth at vertical circle readings of 30°, 150°, 210°, and 330°..	16
Twelve measurements 30° apart at the equator....................	12
Four null values at the south pole of lamp.........................	1
Total number of effective measurements..........................	38

The points thus laid off on the reference sphere are approximately equidistant, being somewhat closer together at the equator than at the poles."

When the lamp is rotated, readings are taken for each 15° or 30° in inclination, from 0° to 90°, and from 0° to 270°. These are integrated values for their corresponding parallels of latitude on the unit sphere.

The mean spherical candle-power from these readings may best be obtained by plotting a distribution curve from the readings, determining the area of this closed curve by means of a planimeter and taking the radius of an equivalent circle as the value for the mean spherical candle-power.

In all tests the voltage of the lamp must be very closely regulated. A storage battery forms the ideal source of current for such purposes. In testing incandescent lamps a standard similar to the lamp being tested is desirable and it should, preferably, be connected to the same leads. Any variation in the voltage of the mains then affects both lamps and the error introduced is slight.

Arc Light Photometry. Owing to the variation of the amount of light given out by an arc lamp in one direction at any time, due to variation of the qualities of the carbons, position of the arc, and also on account of the color of the light, etc., the photometry of arc lamps is much more difficult than that of incandescent lamps. The curves shown in Figs. 10 and 11 are average distribution curves taken from several lamps and will vary considerably for any one lamp. If the arc is enclosed, this variation is not so great.

The working standard should be an incandescent lamp run at a voltage above the normal so that the quality of the light will compare favorably with that of the arc. Since an incandescent lamp deteriorates rapidly when run at over voltage, the standard can be used only for short intervals and must be frequently checked.

Since an arc lamp can be mounted in one position only, mirrors must be used to obtain distribution curves. A mirror is used mounted at 45° with the axis of the photometer, and arranged so as to reflect the arc when in different positions. A mirror absorbs a certain per cent of the light falling upon it and this percentage must be determined by using lamps previously standardized. The length of the photometer bar must include the distance from the mirror to the arc.

The Weber photometer is well adapted to arc-light measurements inasmuch as appropriate screens may be used to cut down the intensity of the light.

A special form of the Matthews' photometer is also used for testing arc lamps.

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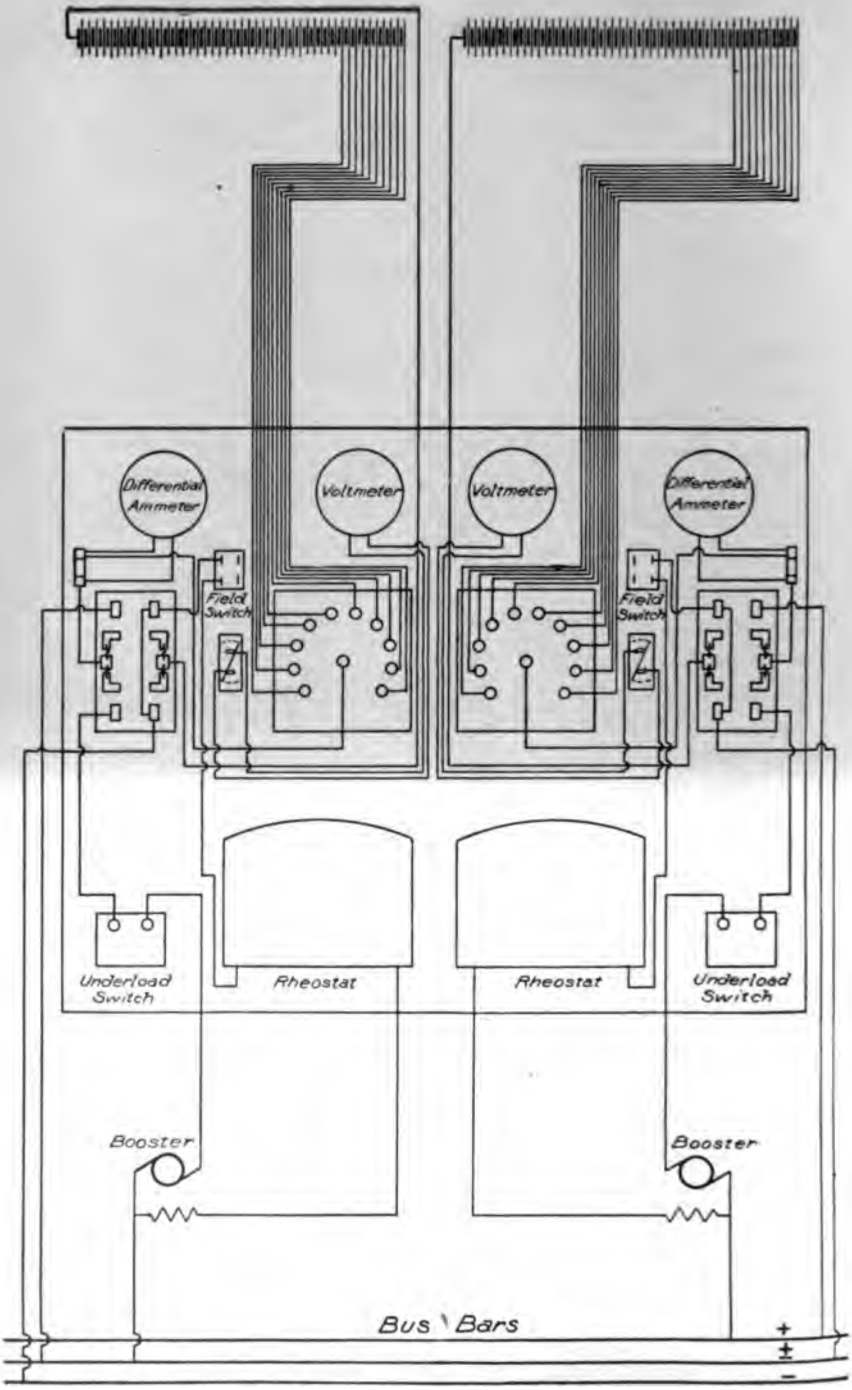


Switchboard Connections for Storage Battery **Auxiliary**

STORAGE BATTERIES.

Storage or secondary batteries, also called accumulators, consist of cells in which a chemical change is brought about by passing an electric current through them, thereby rendering them capable of giving back electrical energy by discharging them until they return to their original chemical condition.

Ordinarily, a storage battery consists, essentially, of two sets of plates suspended in a chemical solution. The plates are of metal or metallic oxide, and the solution is incapable of acting upon them until an electric current is passed from one plate to the other. This current decomposes the electrolyte; one of its constituent elements or radicals goes to one plate, and the remaining constituent to the other, so that when the passage of the current ceases there are two chemical elements or radicals with a tendency to unite, and upon combination the energy evolved appears as an electric current, which flows in the opposite direction to the charging current. This flow of current continues until the cell is restored to its original condition; when this occurs the cell is said to be discharged.

A Primary Cell is one in which electrical energy is produced by the chemical action of one or two solutions on the plates of the cell. When the solutions or plates are exhausted, they are *not* restored to their original condition by the passage of an electrical current.

This reversibility or regeneration is the fundamental difference between storage and primary cells.

An Electrolyte is a chemical compound, capable of acting as an electrical conductor, and while so acting, undergoes chemical decomposition. This phenomenon is called electrolysis.

For example, when hydrochloric acid is decomposed by electrical energy, it is decomposed into the elementary gases hydrogen (H) and chlorine (Cl). The chemical formula for this action is,

$$2H\,Cl + \text{Electrical energy} = Cl_2 + H_2.$$

When sulphuric acid is electrolyzed, it is at first split up into hydrogen (H_2) and the radical sulphion (SO_4); the latter combines with the water of solution present and reforms sulphuric acid (H_2SO_4) and oxygen is liberated. The chemical equations for the above primary and secondary reactions are:

$$2H_2O + 2H_2SO_4 + \text{Electrical energy} = 2H_2 + 2SO_4 + 2H_2O$$
$$2H_2 + 2SO_4 + 2H_2O = 2H_2 + 2H_2SO_4 + O_2$$

The modern theory of electrolysis assumes that in an electrolytic solution there are always free ions which wander around promiscuously, until the application of an electric current directs their wanderings into certain definite directions.

Any salt dissolved in water is ionized, that is, some portion is separated into the two component parts of the salt.

When certain metals such as potassium or sodium are free in an ionized solution they are said to be in an allotropic state, and when the current is passed through the solution, the metal is freed from its allotropic state, and will in such cases, form hydrates, (KOH), (NaOH). The theory also states that the conductivity of electrolytes is due to the presence of these ions, and that the non-ionized portion does not conduct.

In 1802, soon after the invention of the primary cell by Volta, Gautherot demonstrated the fact that platinum wires, after being used to electrolize saline solutions, were able to produce secondary currents. Volta, Ritter, Davy and others noted similar effects, the phenomenon being what is commonly called polarization. In 1859 Planté undertook a series of experiments with the object of studying and magnifying this effect and finally developed the Planté type of storage battery; nearly all successful types of storage batteries of the present day are based upon Planté's invention.

Types of Storage Batteries:

Planté,
Faure,
Combination of Planté and Faure.
Non-lead.

PLANTÉ BATTERY.

This cell was originally made by placing two plates of metallic lead in a vessel containing dilute sulphuric acid. These plates were connected to an electric generator, and a current sent through the cell, which decomposed the electrolyte and oxidized the positive plate. The cell was then discharged; but tne energy obtained was very small, since the action was confined to tne immediate surface of the plates. By repeated charging and discharging first in one direction and then in the other, the oxidation penetrated deeper and deeper into both plates, thus increasing the storage capacity of the cell.

The chief difficulty with the Planté battery was the great length of time required for "forming" the plates, which as just explained consists in converting the surface of the plates into active materials, by repeated chargings and dischargings. This takes a long time and is expensive, as it requires a large consumption of electrical energy. Later on in his investigations, Planté hastened this forming process by pickling the plates in dilute nitric acid, then washing them in a 10 per cent sulphuric acid solution, after which they were electrically formed. One difficulty with the Planté system was that plates well adapted to the forming process were difficult to make.

In 1881 Faure devised the method of pasting the lead oxide or active material directly upon the plates. This largely avoids the tedious forming process; but the plates thus produced are not as durable as the Planté elements, being more likely to disintegrate, because the paste is not an integral part of the plate and there is considerable difference in the coefficients of expansion of lead and of the oxide.

Innumerable forms of storage batteries have been invented, and many of them have been exploited, in which copper, zinc, iron and other metals or elements instead of lead were used; but almost all of those now being manufactured and used commercially are of some lead type. Such being the case, it is safe to assume or infer, that this lead combination possesses distinctive features not present in the other combinations; and upon investigation, it is apparent that these features are that the electrodes, the active materials and the compounds formed from them are, under every normal condition of use, insoluble in the electrolyte employed.

In nearly every other form of battery now on the market, one or even both of the electrodes or materials formed on them are soluble in the electrolyte, and this solubility is detrimental to the storage power and life of the cell.

General Principles of the Storage Battery. Any primary battery will act as a storage battery provided its chemical action is reversible. The ordinary gravity cell, for example, may be regenerated by sending a current through it in the direction opposite to that produced by it. The zinc sulphate and the metallic copper are thus reconverted into metallic zinc and sulphate of copper respectively, the chemical action being

$$ZnSO_4 + Cu + \text{Electricity} = Zn + CuSO_4,$$

which is exactly the reverse of the action in the primary cell. There are, however, practical difficulties in the continued recharging of a spent gravity cell, due to the ultimate mixture of the sulphate solutions and the copper salt reaching the negative electrode, where it is deposited and sets up destructive local action.

In some forms of primary cells, the chemical action liberates a gas that escapes, so that the action is obviously irreversible.

Chemical Action in Lead Storage Batteries. The exact nature of the chemical changes which occur in lead batteries, is not yet fully established. Planté believed the charging action to consist in the formation of peroxide of lead (PbO_2) on the positive plate, and metallic lead on the negative, which were converted into lead oxide (PbO) on both plates by the discharge. Some authorities still maintain this to be the chief reaction; but it has been shown by Gladston and Tribe, and corroborated by subsequent investigations, that the formation of lead sulphate plays an important part.

The probable reaction may be represented as follows:

	Positive Plate.		Electrolyte.		Negative Plate.
Charged Condition	PbO_2	+	$2H_2SO_4$	+	Pb
Discharged "	$PbSO_4$	+	$2H_2O$	+	$PbSO_4$
Charging Current			$\longrightarrow$		
Discharging Current			$\longleftarrow$		

According to the above equations, the active material on both plates is converted into lead sulphate when the battery is discharged. The reasons for believing this to occur are: *first*, chemical analysis shows that lead sulphate exists in the discharged plate, *second*, the density of the electrolyte decreases during the discharge of the cell, corresponding to the consumption of sulphuric acid and the formation of water as shown in the above reactions, *third*, on the thermo-chemical grounds, the combination of lead and oxygen as lead oxide (PbO) does not evolve sufficient energy to account for the E. M. F. or voltage produced.

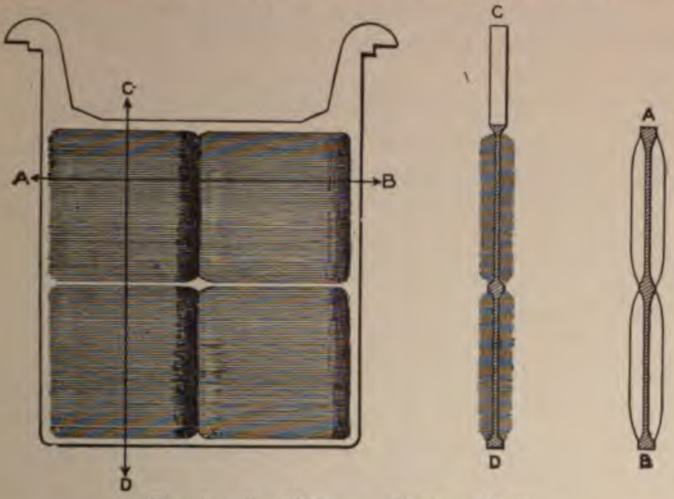


Fig. 1. Gould Storage Battery Plate.

Storage Batteries of the Planté Type. It was noted that the serious objection to the Planté battery was the great length of time necessary to form the plates, and how Planté treated them with nitric acid to hasten this action. Other methods are used to obtain a quickened formation, and are tabulated as follows:

1. *Mechanical Action:* Laminated plates, made up of lead ribbons. The surface of the plate is grooved with some forming tool. Built up of lead wires, etc.
2. *Chemical:* Treating the plates in some pickling bath, to produce initial oxidation.
3. *Electrolytic:* Forming a plate of some compound of lead or an alloy, and either reducing the compound or eating the foreign matter away, leaving a porous lead plate.

The Gould Storage Battery. This battery is made by the Gould Electric Storage Battery Company of N. Y., and the plates are produced by a combination of the first and second methods. The plates or blanks are placed in steel frames and given a reciprocating motion between two revolving shafts which carry grooving discs, giving the plates a surface as shown in Fig. 1. No lead is removed by this process but the surface is ploughed up. It is then subjected to electro-chemical treatment to form the active material. The completed cells range in size from a cell of three plates 3 inches by 3 inches, to one of one hundred and five plates each 15.5 inches by 31 inches, and in capacity in ampere-hours from five to seventeen thousand.

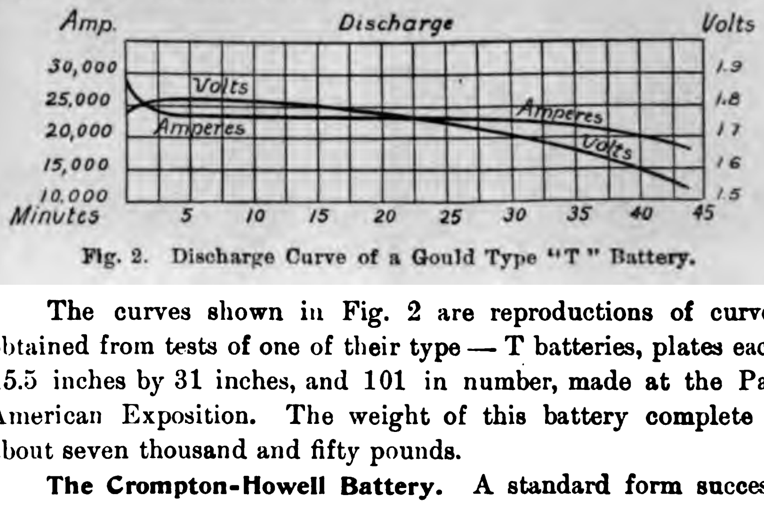


Fig. 2. Discharge Curve of a Gould Type "T" Battery.

The curves shown in Fig. 2 are reproductions of curves obtained from tests of one of their type — T batteries, plates each 15.5 inches by 31 inches, and 101 in number, made at the Pan American Exposition. The weight of this battery complete is about seven thousand and fifty pounds.

The Crompton-Howell Battery. A standard form successfully used in England, is of the Planté type, the plates being composed of a porous crystalline lead, made according to method 3 (see page 5) and afterwards "formed" by repeated charges and discharges. The regular dimensions of the plates are 9 inches by 9 inches by ¼ inch, and the different sizes of cell are made up by varying the number of plates. A cell of this type with sixty-one plates can maintain a discharge of 1000 amperes for thirty minutes without a serious fall in potential.

FAURE TYPES OF STORAGE BATTERY.

As has been stated, the difficulty with the Faure type is the natural tendency it has to disintegrate. Various methods to increase the permanency of the adhesion of the active material have been suggested of which the most important are as follows :

1. Plates are grooved, roughened, or "pocketed."

2. Plates are entirely perforated, the holes being circular, or rectangular, and varying in cross section; some have a uniform section through the grid A, Fig. 3, others are contracted at the center B and again they may be expanded at the center of the grid C.

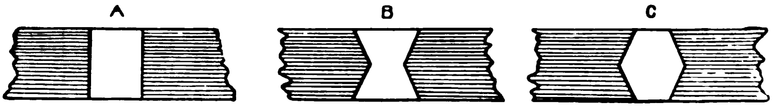


Fig. 3. Different Cross Sections of Faure Plate Perforations.

3. The active materials may be enclosed in either a conducting or non-conducting cage.

4. The plates may be made up entirely of active material.

Faure cells usually have a greater weight efficiency than Planté types because the proportion of active material may be made greater.

The E. P. S. Battery is one of the most important of the Faure type, its name being the initials of the Electric Power Storage Company by which it is manufactured in England. It is sometimes called the Faure-Sellon-Volckmar cell, being made under the combined patents of these and several other inventors.

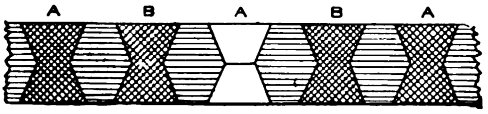


Fig. 4. Section of E. P. S. Battery Plate.

The plates consist of lead grids cast in an iron mold, and have the cross-section shown in Fig. 4. The later types have a thin perforated strip of metal (lead) running across each opening midway between the edges. The holes A in the grid are completely filled with a paste of red lead or minium (Pb_3O_4) and dilute sulphuric acid for the positive, while the paste for the negative consists of minium, or litharge (PbO) and dilute sulphuric acid or a magnesium sulphate solution. These pastes are pressed into the grids and dried.

The plates are hardened in dilute sulphuric acid, after which they are ready for forming. A strong current of 48 hours' duration is required for the positive plate and twenty-four hours is required for the formation of the negative plate. To prevent short circuiting after the cells are set up, the plates have glass rod separators placed between them.

The E. P. S. batteries are made in many different sizes and types, of which the L type is a good example, being used extensively in isolated plants. Data of this type are as follows:

E. P. S. ACCUMULATOR, L. TYPE.

No. of Plates.	Maximum Normal Charge or Discharge Rate.	Capacity Ampere Hours.	Approximate External Dimensions.			Weight Complete with Acid Wooden Cell.
			Length.	Width.	Height.	
7	13 amperes	130	5½ in.	13½ in. for wooden and 12 for glass cell.	18 in. for wooden and 13½ for glass cell.	74 lbs.
11	22 "	220	8			107 "
15	30 "	330	9½			143 "
23	46 "	500	14½			228 "
31	60 "	660	19			286 "

One of the smaller types of the E. P. S. battery is used extensively in England in electric vehicle work.

The Exide Battery is manufactured by the Electric Storage Battery Co., of Philadelphia, chiefly for electric vehicle duty. The plates are of the Faure type, and consist of lead-antimony grids (about 5 per cent antimony) pasted with oxides of lead.

The grid for the positive plate is of the cage type, consisting of thin vertical ribs, the edges of which are flush with the faces of the plate, and connected by small bars of a triangular cross section; the bars on one face are staggered with respect to those on the other side. This finished form is then pasted up with red lead (Pb_3O_4) and formed in the usual way; the thickness of the finished plate is about $\frac{7}{32}$ inch. From this description it is evident that the plate is made up in accordance with method 3 described on page 7, the enclosing cage being of conducting material. The active material is in the form of rectangular pencils extending from the top of the plate to the bottom. The thin flat ribs are on two sides of these pencils and the triangular cross pieces are imbedded in the other two sides which constitute the faces of the plates. The Exide cell is shown in Fig. 5.

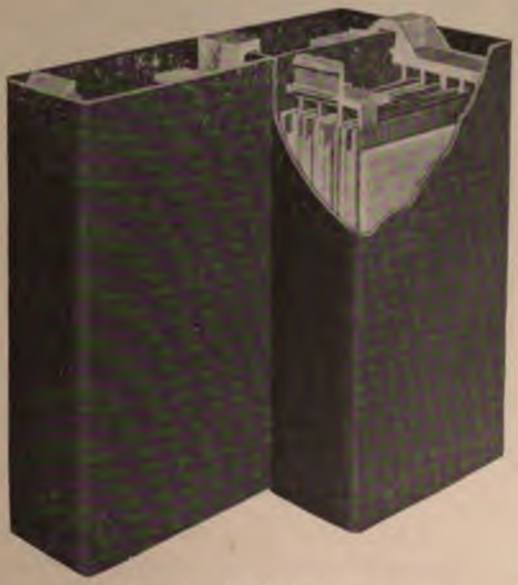


Fig. 5. Exide Battery.

The negative plate consists of a thin antimony lead sheet enclosed by a light frame of cast lead. The body of the sheet is perforated at regular points and very close together. These perforations are not actual punchings (being made by a tool which does not remove the material) but are simply holes torn in the plate leaving the material around the hole in ragged projections which curve back towards the sheet, and form as it were a series of hooks. These projections are formed on both sides of the plates.

The grid is then pasted with litharge (PbO) on both faces; it is held to the plate by the "hooks" as well as being "riveted" by passing through the holes which the projections surround. The thickness of this finished plate is about $\frac{3}{16}$ inch.

When assembled, the plates are placed in rubber jars of dimensions as above, and separated from each other by wooden partitions. In addition a perforated rubber sheet is placed against the faces of the positive plates.

The brougham or hansom battery of this type of cell consists of 44 cells of TV–9 size, having four positive and five negative plates. The weight of this outfit complete with tray is about

DATA SHEET EXIDE CELLS. *

TYPE.	—M. V.—							—P. V.—			
Number of Plates.	7	9	11	13	15	17	19	5	7	9	11
Discharge in Amps for 4 Hours.	21	28	35	42	49	56	63	12	18	24	30
Size of Plates.											
Length (inches).	5¾	same	same	same	same	same	same	4 13/16	same	same	same
Height (inches).	8⅝	same	same	same	same	same	same	8⅝	same	same	same
Outside Measures of Rubber Jars.											
Width (inches).	2 7/16	3¼	4¼	4 11/16	5 3/16	6¼	7 3/16	1 13/16	2 9/16	3¼	4¼
Length (inches).	6 3/16	same	same	same	same	same	same	5 5/16	same	same	same
Height (inches).	11½	same	same	same	same	same	same	11½	same	same	same
Weight in Pounds.											
Elements.	15¾	20¾	25½	30¼	35	40	44¾	9¼	13¼	17¼	21½
Electrolyte.	2½	3½	4½	6½	7	8	8¾	1¼	2¼	3	4½
Complete Cell.	19½	25½	31¼	38½	44½	50	56	11½	17½	21½	27½

* Note: For data on the "Express Type" of exide cell see literature of the Electric Storage Battery Company, Philadelphia.

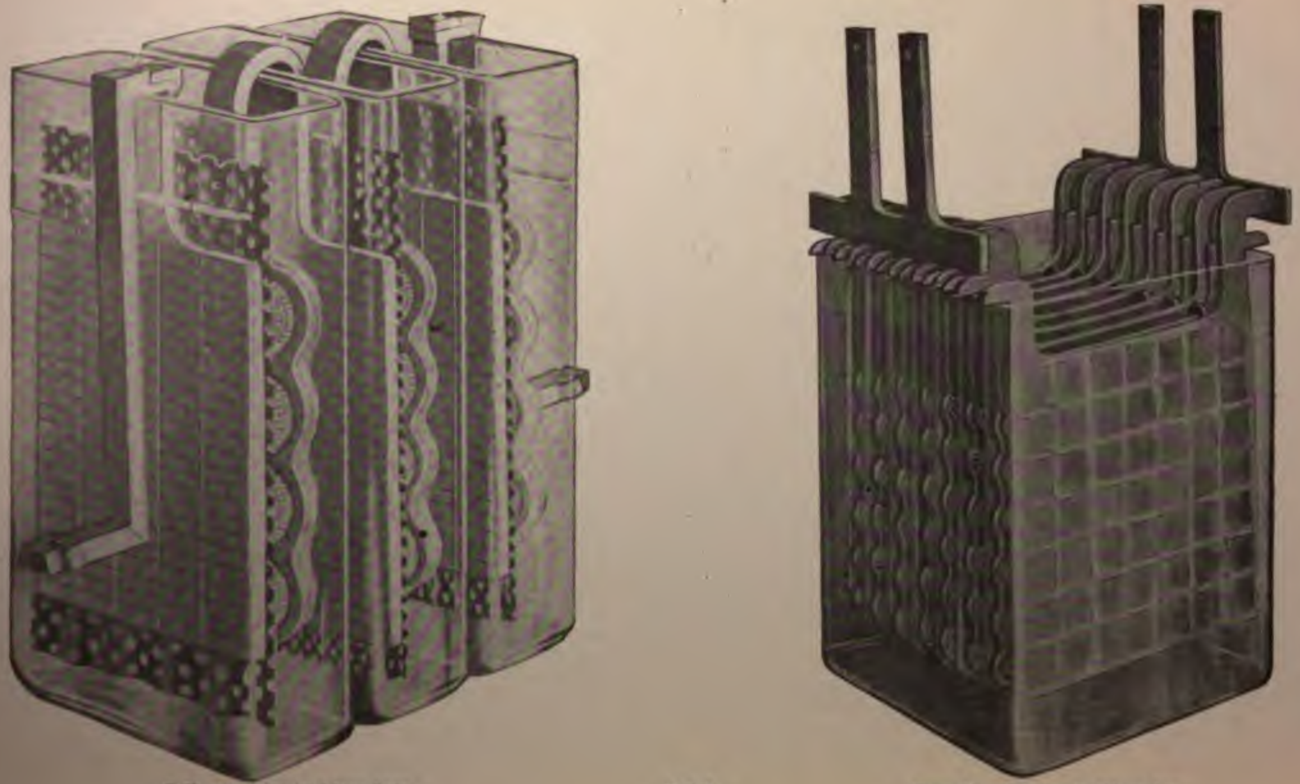
1659 pounds, the capacity 156 ampere hours (4 hour, 39 ampere rate), the average voltage during discharge about 1.98 volts per cell or 87 volts for 44 in series, the total watt-hour output being therefore 13,572 or 8.18 per pound of battery complete including trays.

COMBINATIONS OF PLANTÉ AND FAURE TYPES.

The Chloride Battery, in the form which was manufactured until recently by the Electric Storage Battery Company and allied companies in England, France and Germany, is a compromise between the Planté and Faure types, the positive being a Planté type and the negative of practically the Faure type.

The principal features in the manufacture of this battery are as follows: The first step is the production of finely divided lead, which is made by directing a blast of air against a stream of the molten metal, producing a spray of lead which upon cooling falls as a powder. This powder is dissolved in nitric acid (HNO_3) and precipitated as lead chloride ($PbCl_2$) on the addition of hydrochloric acid (HCl). This chloride washed and dried forms the basis of the material which afterwards becomes active in the negative plate B, Fig. 6. The lead chloride is mixed with zinc chloride, and melted in crucibles, then cast into small pastiles or tablets about $\frac{3}{4}$ inch square and of the thickness of the negative plate, which according to the size of the battery varies from $\frac{1}{4}$ inch to $\frac{5}{16}$ inch. These tablets are then put in molds and held in place by pins, so that they clear each other by .2 inch and are at the same distance from the edges of the mold. Molten lead is then forced into the mold under about seventy-five pounds pressure, completely filling the space between the tablets. The result is a solid lead grid holding small squares of active material. The lead chloride is then reduced by stacking the plates in a tank containing a dilute solution of zinc chloride, slabs of zinc being alternated with them. This assemblage of plates constitutes a short-circuited cell, the lead chloride being reduced to metallic lead. The plates are then thoroughly washed to remove all traces of zinc chloride.

In the new form of negative plate which has replaced the chloride type just discussed, the negative consists of a "pocketed" grid, the opening being filled with a litharge paste; it is then covered with perforated lead sheets which are cast integral with



R.T.—Couples in Glass Jars.

Fig. 6.

Type F—15 Plates in Glass Jar.

the grid. The positive plate is a firm grid, composed of lead alloyed with about 5 per cent of antimony, about $\frac{7}{16}$ of an inch thick, with circular holes $\frac{25}{32}$ of an inch in diameter, staggered so that the nearest points are .2 of an inch apart. Corrugated lead ribbons $\frac{7}{16}$ of an inch wide are then rolled up into close spirals $\frac{25}{32}$ of an inch in diameter, which are forced into the circular holes of the plate.

By electro-chemical action, these spirals are formed into active material, the process requiring about thirty hours; at the same time the spirals expand so that they tend to fit still more closely in the grids. This form of positive is that known as the Manchester Plate.

DATA CHLORIDE BATTERY.

TYPES.	B.	C.		BT.	CT.	PT.	D.		E.		F.		G.		H.	
Size of Plate, inches	3x3	4¾x4		3x4	5x5	8¾x5	6x6		7¼x7¼		11x10½		15½x15½		15½x31	
Number of plates	3	3	7	2	2	2	3	13	5	15	9	27	11	75	21	75
Disch. in Amperes — For 8 hrs.	⅝	1¼	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	400	1480
5	¾	1¾	5¼	1	2	4½	3½	21	14	49	56	182	140	1036	560	2072
3	1¼	2½	7½	1½	3	6	5	30	20	70	80	260	200	1480	800	2960
1							10	60	40	140	160	520	400	2960	1600	5920
Normal Charge Rate	⅝	1¼	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	400	1480
Outside dim. of glass jars, inches — Width	2½	3¼	5¼	1¾	2¼	2½	3¼	11	5½	11	9	No glass jars for these large sizes.				
Length	4	5¼	5¼	3¾	6¼	6	7¼	8¼	9¼	9¾	12¾					
Height	6½	7¼	7¼	6¾	8	12	9½	9¼	11¾	11¾	17					
Outside dim. for lead-lined wooden tanks — Width											13¾	28¼	15½	69¾	25¼	69¾
Length											15	15	19¼	21½	21½	21½
Height											20¾	20¾	26	27¾	48¼	49¼
Wht. of cell complete (lbs.)	5¼	10½	19	3½	7½	13½	19½	64	48¾	112	175					
Ditto. Lead-lined tanks.											250	615	561	3260	1885	5090

Modern types of chloride accumulator are shown in Fig. 6.

In setting up the cells, the plates are separated from each other by special wood partitions, having vertical grooves to facilitate the rising of the gases. Sometimes glass rods are used as separators.

The table gives the data of the various types and sizes of cells. To save space only the smallest and largest [illegible] of each type are given, but in all cases intermediate [illegible] every odd number of plates. The capacities, weights, etc., are of course nearly proportional to the number of plates.

The smaller sizes are provided with either rubber or glass jars, and the larger ones, from F up, with lead-lined tanks.

The Tudor Cell has been very extensively used in Europe, and to some extent in this country, although it is no longer manufactured here. The American patent rights are controlled by the Electric Storage Battery Company.

The plates consist of rolled, grooved sheets as shown in Fig. 7, A being the hollows or grooves into which the paste is set and B the lead frame. The thickness of the plate between opposite grooves is about .12 inch for the positive, and about .06 inch for the negative. The width of grooves on the positive plate is also about .12 inch, while on the negative it is about .08 inch. The grooves are first coated with a thin layer of peroxide of lead (PbO_2) by electrolysis, and then packed with the oxides as required; the plates are then rolled to "fix" the paste. This treatment of the grid with an electrolytic bath before applying the active material, is covered by U. S. patent No. 413,112.

TUDOR CELLS.

Type.	Available Capacity.	Maximum Current in Amperes.		Dimensions of Cells in Centimeters.			Total Weight.
	Amp. Hours.	Charge.	Discharge.	Length.	Width.	Height.	Kgms.
I	26	6	8	12	21	35	10
V	91	21	28	30	21	35	30
X	270	54	72	42	42	55	110
XIV	630	126	168	74	42	55	230

In addition to those given above, all of the intermediate sizes are made.

A battery of larger cells is in use in the Head Place Station of the Edison Company of Boston, Mass., a description of which is given in the Electrical Engineer (N. Y.) of Sept. 18, 1895. The plant contains two batteries of 72 cells each. Each cell consists of a lead-lined wooden box, 3 feet 10 inches long, 3 feet 4 inches wide, and 3 feet deep, in which are suspended 18 positive and 19 negative frames. Each positive frame is composed of 16 plates 7 inches square; while each negative frame has 4 plates 14 inches square, thus giving an enormous surface in each cell. The plates are secured in their respective frames by lead strips. The frames are held in position about $\frac{1}{2}$ inch apart by vertical glass tubes, and rest upon thick glass plates placed on edge in the bottom of the cell; the frames being thus raised 6 inches above the floor of the cell. It is said that these two batteries combined are capable of supplying 6,600 amperes at 110 volts for $1\frac{1}{4}$ hours, which would usually cover the period of very heavy load. This is an output of 726 kilowatts, or nearly 1,000 horse-power for $1\frac{1}{4}$ hours, being a remarkably high discharge rate.

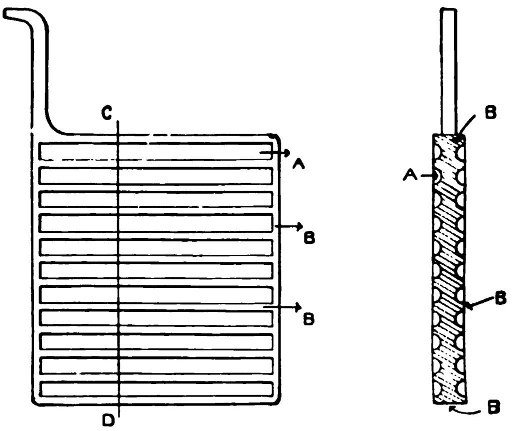


Fig. 7. The Tudor Battery Plate.

Formerly it was used in central stations, particularly where the rate of discharge was great, as for example when the total time of discharge was only $1\frac{1}{2}$ to 4 hours. For this work the negative plates were of the chloride type, the positives being the heavy Tudor plates described above.

Lithanode. Mr. Desmond Fitzgerald has made storage batteries with a positive plate consisting entirely of active materials made up of litharge (PbO) mixed with ammonium sulphate $(NH_4)_2SO_4$ which he pressed into the required shapes. This plate is converted into peroxide by chemical treatment. The negative of this cell consists of the ordinary lead plate. While this cell has an exceedingly high is not of much commercial importance, though used considerably in laboratory work.

It is the tendency in Europe to make the positive plate of the Planté form and the negative of the Faure or pasted type. The reason for this is that while the Planté form makes an excellent positive, the pasted plate is better for a negative.

The practice in lead batteries is to make the negative plate of greater capacity than the positive, as the charging and discharging of a cell in service tends to produce or form more active material on the positive plate, whereas the negative plate is made to decrease, so that allowance for this is made as above stated.

Storage Batteries Containing Metals other than Lead. It has already been stated that almost any primary cell will act more or less perfectly as a secondary cell; as, for example, the common gravity battery. A great many have been devised in which the lead in one or both of the plates has been replaced by some other metal. For example, Reynier made the negative plate of zinc instead of lead, this zinc in discharging being converted into zinc sulphate, which dissolved in the electrolyte. The substitution of zinc for lead secures an increase in initial E. M. F. from 2.2 to 2.5 volts, and also allows of a considerable reduction in weight; since for the storage of a given amount of energy the weight of the zinc required is much less than that of the equivalent lead. A difficulty with this type of cell is the formation of "trees" of zinc on the negative plate during the charging process, which are likely to fall off or extend across to the positive plate, thus short-circuiting the cell.

Another difficulty is the difference in density of the solution between the top and bottom of the plates, the tendency being to exhaust the zinc sulphate from the upper portion of the liquid during charging. In order to avoid this trouble the plates have been arranged horizontally, so that the density would be uniform for each plate; but the difficulty then arises that the gases which form to a certain extent in almost all batteries collect between the plates and interfere with the chemical action and the passage of the current.

A similar type of cell has been manufactured by the Union Electric Company of New York, in which the negative plates consist of thin sheet copper covered with an amalgam of zinc, and the positive plates are made up of laminæ of lead held together by leaden rivets and perforated with numerous small holes, these positives being formed by the Planté process.

Waddell-Entz Accumulator. The copper-alkali-zinc primary battery of Lalande, Chaperon and Edison being reversible in action, can be used as a storage battery. Waddell and Entz have constructed accumulators on this principle. When discharged, the positive plate consists of porous copper; on charging the electrolyte is decomposed, metallic zinc being deposited on the negative plate. the porous copper of the positive plate is oxidized, and the liquid becomes converted into a solution of caustic potash (potassium hydrate).

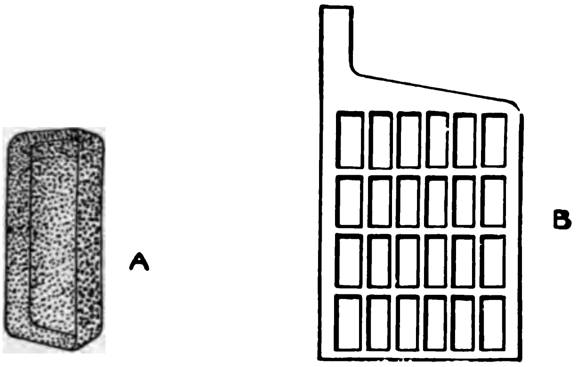


Fig. 8. Construction of Edison Battery Plate.

This storage battery has been used with considerable success for traction purposes, but its E. M. F. is so low, being only about .7 volt, that it would require 170-180 cells for the ordinary 119 volt electric-lighting circuit, allowing for loss of potential in the battery and conductors. This number is three times as great as is required with the lead battery. This is a serious objection in this or any other low voltage cell.

The Edison Storage Battery manufactured by the Edison Storage Battery Company of Newark, N. J., consists of a positive plate of super-oxide of nickel (NiO_2) and a negative plate of iron, suspended in about a 20 per cent solution of caustic potash (KOH).

The mechanical construction of both plates (positive and negative) is the same, and the grids are made of nickel-plated steel, shaped as represented at B, Fig. 8. Each opening in the grid is filled with a perforated shallow pocket A or box of nickel-plated steel which contains the active material, and projects out beyond the body of the grid.

The active material is made up in the form of briquettes; one briquette being placed in each pocket. A perforated cover of nickel steel is placed over each pocket. After the plates are fully assembled they are subjected to a pressure of about 100 tons, which firmly forces all parts into a practically solid mass, making good electrical contact between the pockets and the grid, at the same time turning the edges of the pockets over their respective covers. The active material or briquette consists of a finely divided compound of nickel mixed with about an equal amount of flaked graphite, for the positive plate, and for the negative plate it consists of a finely divided compound of iron, with an equal amount of flaked graphite. This graphite has no chemical connection with the action of the cell but is used simply to increase the conductivity of the briquettes.

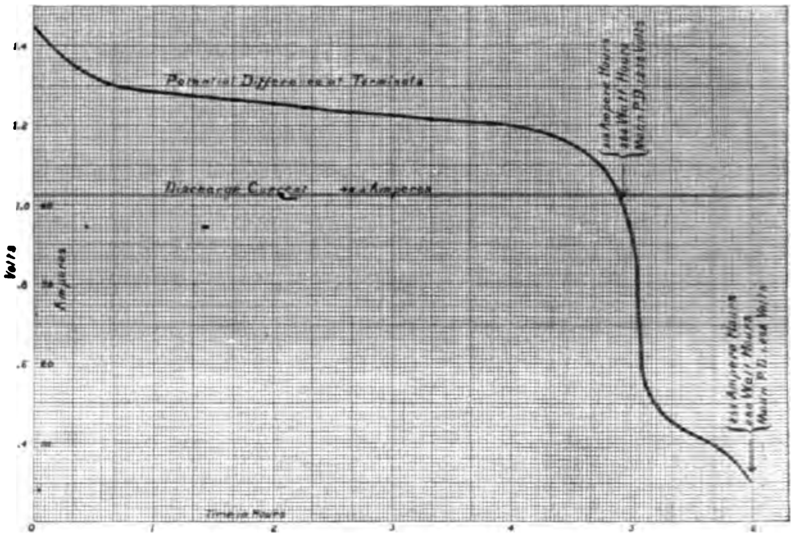


Fig. 9. Curve of Voltage of Edison Cell During Discharge.

The finished plates have a thickness of about $\frac{1}{40}$ inch across the web, and across the pockets of about $\frac{1}{10}$ inch.

The size of the plate varies with the capacity of the cell, having a greater or less number of pockets. The containing jar is also made up of nickel-plated steel sheets.

The initial voltage of discharge after recent charge is 1.5 volts.

The mean voltage of full discharge is 1.1 volts.

This cell has an energy capacity or weight efficiency of 14 watt-hours per pound of complete cell.

Charging and discharging rates are alike, that is to say, the cell may be charged at a normal rate in 3½ hours; or it may be charged at a high rate in one hour, without apparent detriment beyond lowering the efficiency.

The current enters the cell at the positive plate and oxidizes the nickel compound to the peroxide state, and reduces the iron compound in the negative plate to spongy iron.

The electrolyte in this cell simply acts as a path for the passage of the oxidizing and reducing ions, and its own chemical composition does not change.

The cell is not appreciably influenced by changes in temperature. It is claimed that it may be fully discharged to the zero point of E. M. F. without injury, can be charged in reverse direction, then recharged to its original condition and suffer no loss in its storage capacity. The curve given in Fig. 9 shows a six hour discharge of an experimental cell, at a constant current of 42.5 amperes.

MANAGEMENT OF STORAGE BATTERIES.

In describing the handling of storage batteries, the various types of lead cells will be considered, as they constitute a very large majority of cells in commercial use.

The Battery Room. In the installation of a battery, the first point to be considered is its location. The room for this purpose should be dry, well ventilated and of a moderate temperature, otherwise not only will the evaporation of the electrolyte be excessive, but if the temperature be very high, the plates themselves will be affected and their life shortened. The floor, walls and ceiling must be of some acid proof material, brick or tile being preferable, and the floor so made as to drain readily; an outlet being provided for the drainage system. If the room should be an old one, and have a wooden floor, the floor should be coated with asphaltum paint, and lead trays placed below the batteries; any wood work or iron work in the room should be likewise treated.

The room should be sealed from the rest of the building, and located near the generating machinery and distribution switchboard, so that the copper cables may be low in cost. The windows in the battery room should be either of ground or painted glass, so that no direct rays of the sun may strike the cells, as the heat may crack the cells (glass) or increase the activity of the acid, which is not desirable.

In case the battery installation is in a cold climate, some device for keeping the electrolyte at a moderate temperature must be used. A simple plan is to suspend an incandescent lamp in the cell and have it connected to some automatic device which will put it out when the electrolyte is at the desired temperature or light it when the electrolyte is too cold.

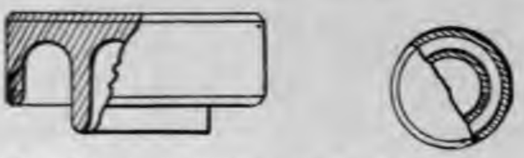


Fig. 10. Glass Insulator for Battery Support.

Setting up the Cells. The battery is usually placed on the floor, or upon strong wooden shelves; Fig. 11 shows a form adapted to cells of medium size. Iron stands are sometimes used for large and heavy cells, but they must be protected from acid fumes and drip by several coats of an acid-proof paint. Wooden stands should be varnished, painted or soaked in paraffin for the same reason. It is important to have every cell accessible for inspection, cleaning and removal, it being desirable to reach both sides of the cell. There should also be sufficient head room between shelves so that the elements may be lifted out.

It is highly important that the cells be thoroughly insulated from each other, to avoid leakage of current. This is accomplished by standing each cell on four insulators of porcelain or glass of the design shown in Fig. 10. Porcelain is preferable to

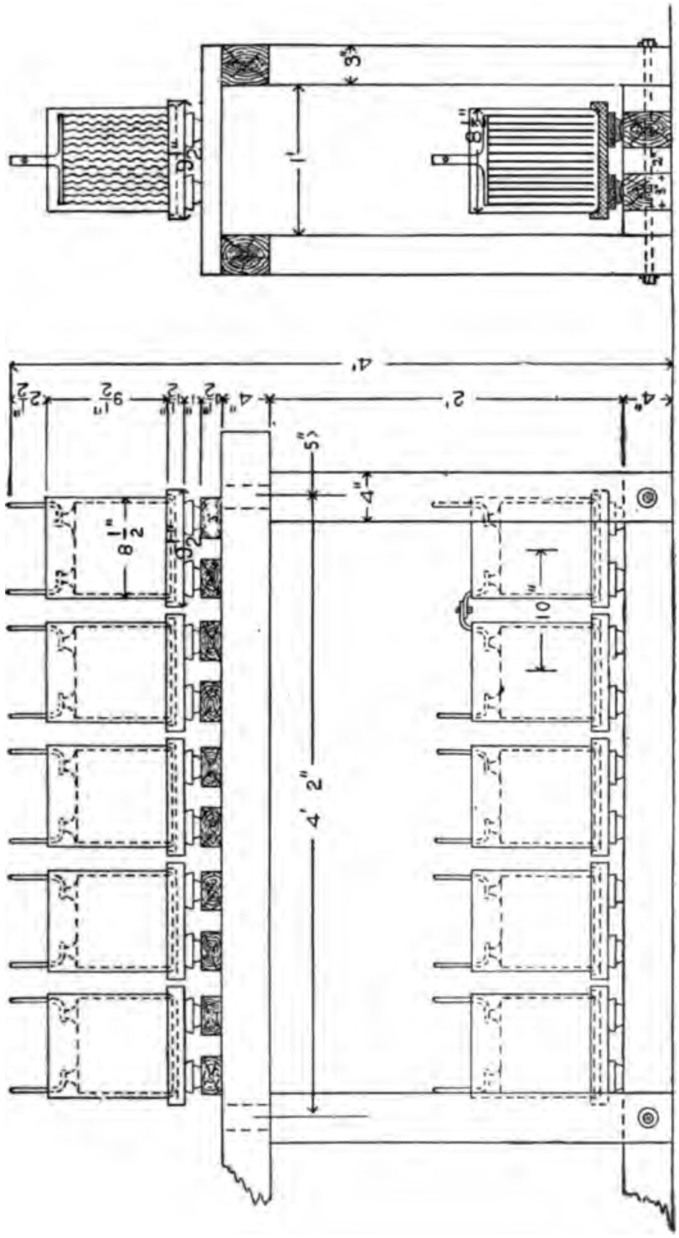


Fig. 11. Shelf Construction for Battery Support.

glass as the latter is sometimes pitted by the action of acid fumes.

Lead-lined tanks are usually set as follows: The floor is covered with a layer of glazed tile or brick; on this are placed two wooden stringers about 3 x 4 inches carefully painted with asphaltum varnish or some acid-proof paint. On these are set four insulators held in place by wooden pegs which are kept in position by pouring melted sulphur around them. On top of these are placed the battery tray and battery as indicated in Fig. 11.

Oil insulators were at first used, but oil collects and holds dust, and as dust is likely to cause leakage they are no longer used.

For very large lead tank outfits a double system of the supporting construction shown in Fig. 11 is used, but with individual stringers for each cell.

Glass cells are often set on wooden trays, which are filled with sand to distribute the strains and absorb the drip. Saw-dust was also used, but it becomes carbonized by the acid drip, and as this is likely to cause leakage, it has been abandoned.

In connecting the cells, which are usually put in series, great care should be taken to join the positive terminal of one cell to the negative of the next and so on. The color of the plate is the best indication of its polarity, the positive plate being a light brown when discharged and a chocolate color when charged, while the negative varies from a dark slate to a light slate color.

It may be noted at this point that the nomenclature, concerning storage batteries, is different from that of primary cells. The positive plate in the former is the peroxide plate (brown) and is that one from which the current flows out in discharging, whereas that would be the negative plate of a primary battery.

The positive pole or terminal in a storage battery is an extension of the positive plate, and is connected to the positive terminal of the dynamo in charging; consequently there is much less cause for confusion of terms than there is in the primary cell.

It is well to test the polarity of each cell and of the circuit before making connections. This may be done with any form of pole tester, or by the positive expedient of dipping the two terminals in dilute sulphuric acid, the one from which the most bubbles arise being negative. The connections should be scraped clean and screwed up very tight, being also coated with acid-proof paint to avoid corrosion. The most satisfactory way to connect up a cell is to weld or "burn" the positive terminal to the negative terminal of the next cell, though soldered connections are good.

This soldering is done as follows: Two strips of lead and the terminals to be connected are very carefully cleansed; the lead strips are then clamped to the terminals, a mold placed around the joints and molten lead poured into it.

The Electrolyte. Practice varies considerably as to the strength of solution to use. Chemically pure sulphuric acid is poured into water until its density becomes about 1.2, and then the mixture is allowed to cool before pouring it into the cells. The electrolyte should completely cover the plates. Cells for vehicle work use an electrolyte with density as high as 1.3. It is important to use perfectly pure acid and water, as impurities will cause local actions and ultimately destroy the plates.

It is well to remember that water should never be poured into sulphuric acid, as it is likely to cause the liquid to be thrown out violently.

The advantage of a strong solution is its lower resistance; but it is likely to produce the very objectionable effect of "sulphating."

The density of the electrolyte falls immediately after filling a cell, since some of the acid is taken up by the plates; but it rises again in charging; for example from 1.17 to 1.2. It is convenient to keep a hydrometer in several cells to observe the density of the electrolyte, not only at the beginning, but as a permanent indicator of the amount of charge and general working conditions.

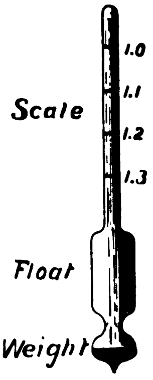


Fig. 12. The Hydrometer.

The hydrometer is an instrument for determining the specific gravity of a liquid, and consists of a weighted bulb and an upright glass rod, bearing a scale, the unit point being fixed by the distance to which it sinks in pure water at 4°C. Readings above this point are for solutions of lower specific gravity than water, and those below it are for solutions of a higher specific gravity. For storage battery work the specific gravity of the electrolyte is always between 1.1 and 1.3, hence we require only a certain portion of the scale as represented in Fig. 12.

Charging. The charging should begin immediately after a new cell is filled with the electrolyte, otherwise the plates are likely to become "sulphated." The first charge differs from subsequent regular charges in that it should be at a rate (lower than normal) that will not cause the temperature of the cell to reach 100°F, but in all other respects it is the same.

Indications of Amount of Charge in a Storage Battery:

1. The E. M. F. rises from 1.7 volts, which is the minimum value to which a lead cell should be discharged, to approximately 2.5 volts when fully charged, although this value may be made a trifle higher or lower, depending upon the rate of charge and temperature of cell. The rise is quite gradual, but more rapid near the beginning and end of the charge, as indicated in Fig. 13. When the cell is fully charged, the E. M. F. becomes constant and the curve approaches a horizontal line as shown. The charging should then be stopped as any more energy passed through the cell is simply wasted in producing gases. The external voltage is higher in charging than in discharging because of the internal resistance of the cell and resulting I R drop, which must be overcome in charging.

The measurements of voltage should always be made when the current is flowing either in charging or discharging.

The E. M. F. on open circuit has little practical significance.

2. *If a record is kept* of the exact number of ampere hours of charge and discharge, the actual amount of energy in the battery at any time is known, due allowance being made for leakage and other losses. For this purpose any integrating instrument such as the Thompson recording wattmeter may be used.

3. *The density of the electrolyte* gradually rises during the charging operation, Fig. 13; the density when charged being about .025 higher than when discharged. There is a lag in the change of the density of the electrolyte, the acid not being absorbed or given off at once by the plates, hence a little time should be allowed before taking any hydrometer reading as final.

4. *Bubbles of gas are given off* freely when the battery is fully charged, since the material of the plates is then no longer

able to take up the oxygen and hydrogen which tend to be set free by the electrolysis; these bubbles give the electrolyte the appearance of boiling, and often they are so fine that the liquid looks almost milky white, particularly in a cell which has not been very long in use.

5. *The color of the positive plates* varies from a light brown on active parts to a chocolate color when fully charged, and to nearly black when overcharged. The negatives vary from pale to dark slate color, but they always differ in color from the positives. This indication of the amount of charge is acquired by experience, but is quite definite after one becomes familiar with a particular battery.

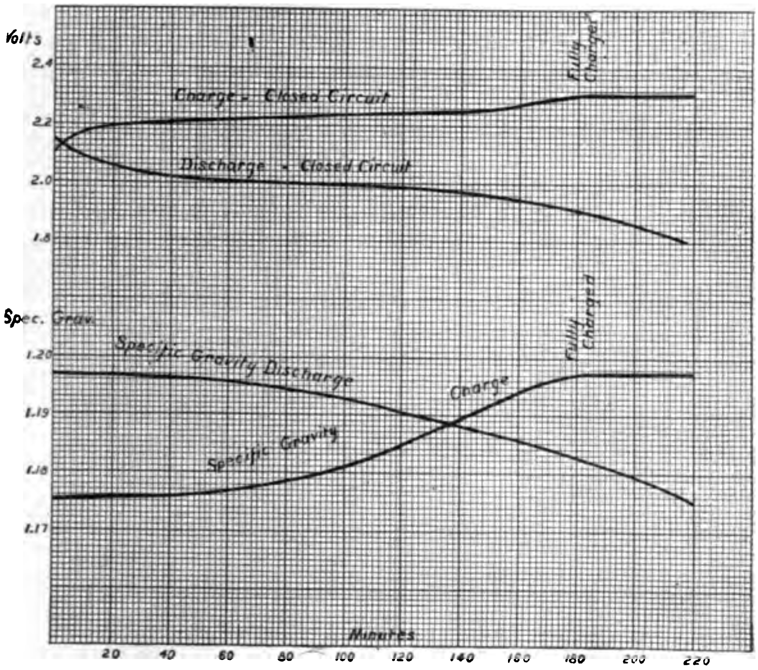


Fig. 13. Curves Showing Variations in Sp. Grav. and Voltage in a Storage Battery During Charge.

6. *Cadmium Test.* The apparatus for making this test consists of a small piece of cadmium, say $\frac{5}{8}''$ x $\frac{5}{8}''$ x $\frac{1}{32}''$ mounted as in Fig. 14. A glass tube contains the conducting wire, wax being used to protect the soldered joint of copper and cadmium. Cad-

mium is used because it will give reliable readings of the E. M. F. of the positive and the negative plates, with respect to itself. In this way a relative condition of the battery and also of each plate can be determined.

With normal conditions of cell, when fully charged and in open circuit, the difference of potential between the positive and the cadmium piece is 2.5 volts or nearly so, and between the cadmium and the negative plate is zero or nearly so. In fact it is sufficient if the sum of the readings is about 2.5 volts.

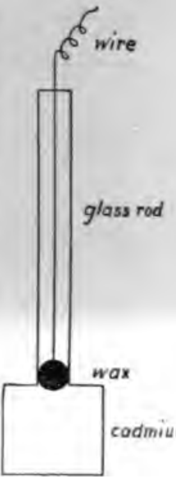


Fig. 14. The Cadmium Tester.

To avoid false conclusions in making a cadmium test, hydrometer, temperature and charge data should be noted. The cadmium test is usually made at the center of the cell to get a uniform current distribution. This test gives readings the sum of which is less than 2.50 volts, when hydrometer tests, temperature and charge data show that the cell is not fully charged; but if the hydrometer, temperature, and other data show the charge to be completed, and the cadmium gives .1 volt or more below 2.5 volts, the defective plate is readily determined by individual cadmium readings. For example, suppose we have a cell in which all conditions tend to show full charge but the potential difference is low. A cadmium test is taken and whichever plate shows the falling off from normal reading, that plate is the defective one, and should be examined for some of the troubles that will be discussed later.

In some cases the cadmium reading with respect to both plates may approach zero; this is caused by a short circuit in the cell which should be found and removed immediately.

In practice it is advisable to have the cadmium wet before the test is made as the readings increase when cadmium is first placed in the electrolyte. The simplest way to accomplish this is to keep the cadmium tester in a beaker of distilled water when not in use. All foreign matter should be carefully removed from the cadmium as it might affect the results. If gas bubbles collect on the cadmium they should be taken off, as they tend to lower the readings.

The proper rate of charge depends upon the size and type of cell, and is usually specified by the manufacturer in each case, since it is merely an empirical fact, being determined by the construction of the plates.

The current for charging is ordinarily obtained from a direct current dynamo, but any other direct current source may be employed. The potential required for charging must exceed that of the battery, which, during the operation acts as a counter E. M F., the expression being $I = \frac{P - e}{R}$, in which I is the current, P the potential applied to battery terminals, e the counter E. M. F., and R the internal resistance of the cell. Usually P is 5 to 10 per cent greater than e, in order to cause the necessary charging current to flow through the resistance R of the cell.

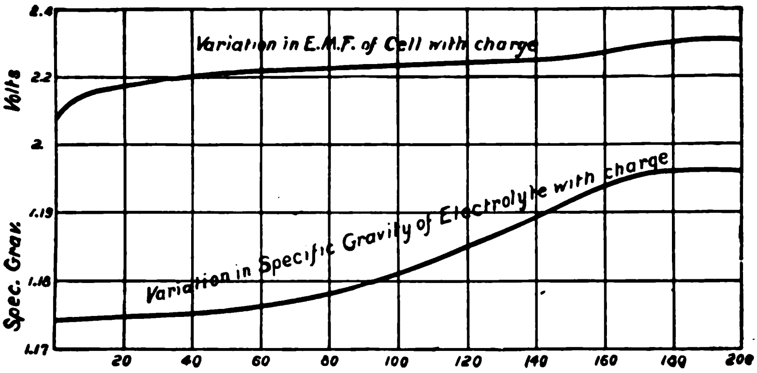


Fig. 15. Curve Showing Increase of E.M.F. in a Charging Cell.

In practice P is regulated until the required charging current I is obtained.

The above equation, put into form of $R = \frac{P - e}{I}$, enables the internal resistance R to be calculated, but as this varies considerably with the temperature, and with different states of charge, its exact value is not often considered.

Another form of the above equation, $e = P - IR$, shows that the true E. M. F. of the battery is less than the charging voltage by an amount equal to the product of the charging current and the internal resistance. Conversely, in discharging, the total

E. M. F. of cell is greater than the difference of potential P between its terminals by the same amount, that is, $e = P - IR$. Hence it is necessary to know I and R, or to measure the voltage when the circuit is open (in which case $I = 0$), in order to find the real E. M. F. of cell. This applies to each individual cell as well as to the entire battery, and is important in determining the amount of charge or working condition of a particular cell.

If the charging voltage P be kept constant, it is evident from the above equtations that the current I will gradually decrease, since the C. E. M. F. or *e* of the cell steadily rises as shown in Fig. 15. This effect is counteracted somewhat by the fact that the internal resistance R also diminishes, owing to the density of the electrolyte increasing. This gradual reduction in the strength of the charging current is considered desirable by some authorities, since it enables the cell to take a greater charge than if the current were maintained at full strength. On the other hand, this diminishing charge makes it difficult to keep account of the exact number of ampere hours supplied to the cell; hence in ordinary commercial work it is considered simpler to charge with a constant current, and if it is desired to keep the cell temperature down, the current is decreased near the end of the charge. The charging operation may be continued until the battery is fully charged as shown by the indications already stated. Since most types of cells are not injured by a slight overcharging at a moderate rate it may even be carried a little beyond the charged point, as it tends to remove "sulphating." A considerable overcharge should be avoided as it causes excessive formation of gas bubbles in the active materials, is likely to heat the cell and ever cause disintegration and buckling of the plates.

Discharging. A storage battery is in most cases discharged within a few hours after being charged, as, for example, in electric lighting, when the engine and dynamo are run during the day for charging the battery which supplies current to the lamps during the night. But a portable battery for feeding lamps might be required to retain its charge for several days. The loss of charge in any battery standing on open circuit is about 25% in one week, but for one day or less it is quite small.

Even when the discharge occurs immediately, the average

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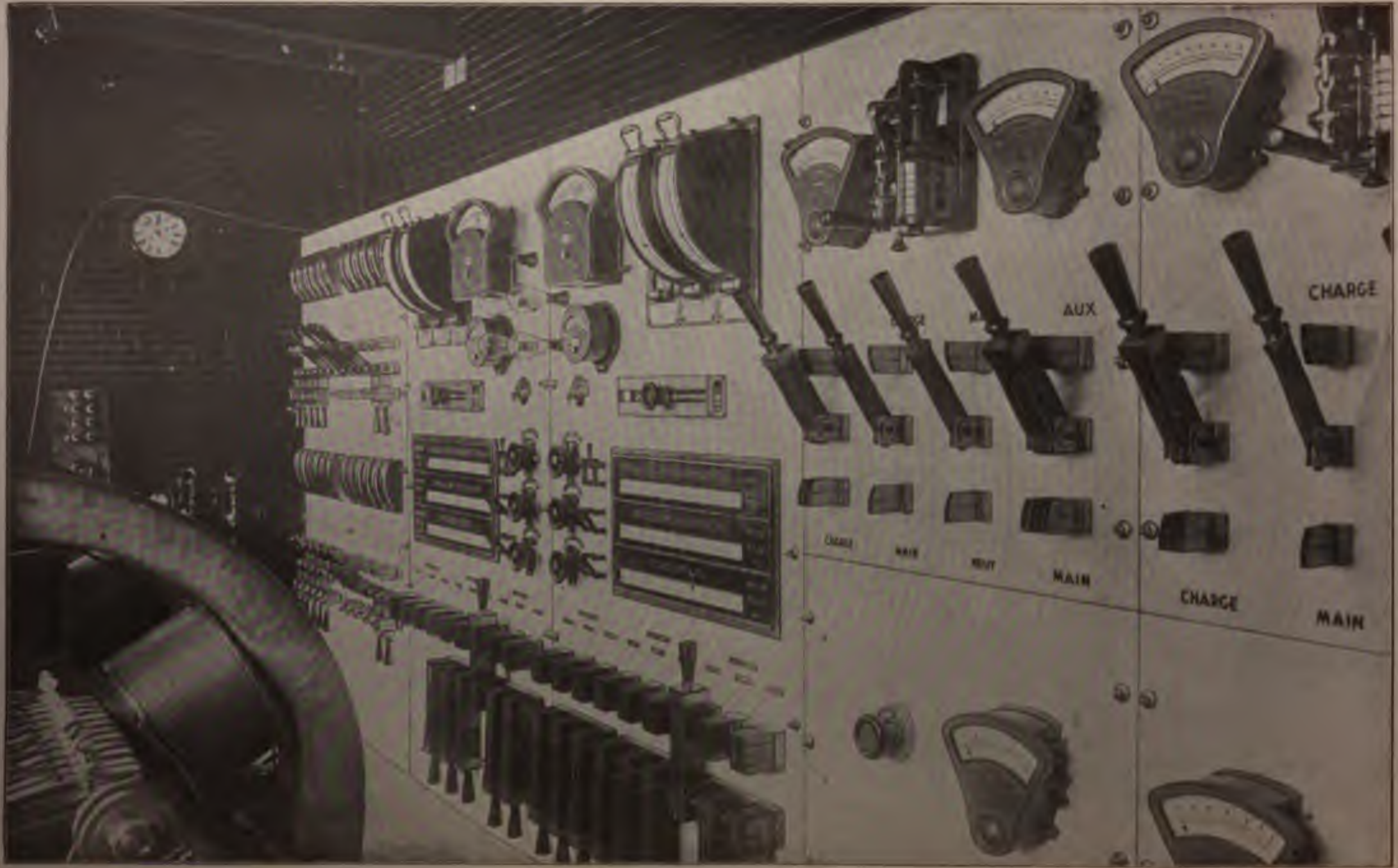


Storage Battery Switchboard

voltage and the ampere-hours obtained are less than for the charge, as explained under "Efficiency." The loss referred to is additional, depending upon the time.

The operation of discharging is naturally the converse of charging, the changes which have been described as occurring in the latter take place also in the former, but in the reverse order. The normal rate of discharging is usually equal to that of charging, but may be somewhat greater. In some cases it is necessary to discharge at higher rates, but by so doing a percentage of the capacity in ampere-hours is sacrificed.

For example, a cell whose normal or eight-hour discharge rate is 100 amperes, can easily be discharged at 400 amperes for one hour, but only 50 per cent of the cell's capacity in ampere-hours is obtained at the latter rate.

An excessive discharge rate is injurious to most types of storage battery plates since it tends to disintegrate the plates, and abnormally heats the electrolyte, which hastens the disintegration; it is therefore advisable to protect the battery with fuses or an automatic circuit breaker.

A storage battery *should never be discharged completely*, as it is very likely to become "sulphated," or otherwise injured; and moreover the E. M. F. falls so rapidly towards the end of discharge that the current would be of no practical value. The limit of discharge is usually considered to be the point at which the E. M. F. drops to 1.75 volts, though when cells are used at the one-hour rate the limit of discharge is 1.6 volts.

A battery should never be allowed to stand in a discharged condition, but should be recharged immediately.

The charge usually left in a storage battery is from 10 to 30 per cent of the total capacity, depending on the rate of discharge, but this involves no considerable loss of energy or efficiency, since it remains in the battery each time and the charging begins at that point.

The Efficiency of Storage Batteries. The efficiency of any apparatus is the ratio between what it gives out and that which it consumes. In a storage battery it is the ratio of the amount of discharge to what is put in to bring the battery back to its original condition after a discharge.

In the first place, the "ampere efficiency" or more properly the "ampere-hour efficiency" which is the ratio of current in ampere-hours drawn from the battery to current in ampere-hours put into the battery is quite different from the watt-hour efficiency. The latter is the real efficiency, since it considers the energy, and includes the voltage as well as the ampere-hours. Ampere efficiency may be scientifically interesting as showing the action of a battery; but it is not of much commercial importance. This is likely to be used either through ignorance or intention to give a false idea since the ampere efficiency is often 15 per cent higher than the watt efficiency.

Another difficulty with the ampere efficiency is the fact that it is possible to obtain an apparent efficiency of over 100 per cent from a storage battery. Since a certain amount (about 25 per cent) of charge is always left in the cell, it is possible to draw apparently more ampere-hours of current than were put in it, by simply discharging the cell more than usual.

This matter has been investigated by Ayrton, who states:

"If an E. P. S. accumulator be over and over again carried around the cycle of being charged up to 2.4 volts, and discharged down to 1.8 per cell, the charging and discharging currents being the maximum allowed by the makers, viz., .026 ampere per square inch of surface in charging, and .029 ampere per square inch in discharging, the working efficiency thus obtained may be 97 per cent for the ampere-hours, and 87 per cent for the watt-hours. If, on the contrary, the cell be constantly charged up before being tested, then for the first few charges and discharges between the above limits, and with the same current density in charging and discharging, even the energy efficiency may be as high as 93 per cent; whereas if the accumulator has been left for some weeks, then, although it was left charged, the energy efficiency for the first few charges and discharges will be as low as 70 per cent."

In general practice it has been found that the efficiency of storage battery plants, when in good condition, varies from 75 to 80 per cent. For instance, referring to the battery plant at the Edison Electric Company station in Boston, a series of tests made there shows the battery installation to have an efficiency of 75 per cent.

Depreciation of Accumulators. The depreciation is claimed to be as low as 5 per cent per annum; in fact both the Tudor and Chloride battery installations at the Boston Edison Company's plants are insured and kept in repairs by the makers for 4 per cent per annum of their total original cost. This figure is as low as the maintenance of the very best steam or electrical machinery. One of the largest electrical manufacturing companies in this country has in use a storage battery equipment which, for the past eight years, has not cost a cent in the way of repairs to, or renewals of, plates. On the other hand, the life of storage batteries in traction or automobile work has in some instances not exceeded six months, though it is claimed that these cells were only in an experimental stage. One must be somewhat guarded, however, in accepting low figures of this kind since from their nature the plates are very easily injured and difficult to repair. It would be very unwise for any one to purchase a battery without the makers' guarantee, to allow less than 10 per cent for its annual depreciation, and this does not include interest, taxes, or other fixed charges.

It has been the practice of several storage battery manufacturers to insure their battery equipments for 6 per cent per annum of their first total cost. This insurance is a maintenance contract calling for inspection and any repairs necessitated through normal use of cells.

TROUBLES AND REMEDIES.

The most serious troubles which occur in storage batteries are sulphating, buckling, disintegration and short circuiting of the plates. These can usually be avoided, or cured by proper treatment if they have not gone too far.

Sulphating. The normal chemical reaction which takes place in storage batteries is supposed to produce lead sulphate ($PbSO_4$) on both plates when they are discharged, their color being usually light brown and gray, due to presence of the PbO_2 still on the positive plate. But under certain circumstances a whitish scale forms on the plates, probably consisting of Pb_2SO_5. Plates thus coated are said to be "sulphated." This term is, therefore, somewhat ambiguous, since the formation of a certain proportion of ordinary lead sulphate ($PbSO_4$) is perfectly legitimate, but the word has acquired a special significance in this connection.

A plate is inactive, and practically incapable of being charged, when it is covered with this white coating or sulphate, as it is a non-conductor.

The conditions under which this objectionable sulphating is likely to occur are as follows:

(*a*.) A storage battery may be overdischarged, that is, run below the limits of voltage specified, and left in that condition for some time.

(*b*.) A storage battery may be left discharged for some time, even though the limits have not been exceeded.

(*c*.) The electrolyte may be too strong.

(*d*.) The electrolyte may be too hot (above 125° F).

(*e*.) A short circuit may cause "sulphating" because the cell becomes discharged (on open circuit) and when charging it receives only a low charge compared with the other cells of the series. A battery may become overdischarged or remain discharged a long time on account of leakage of current due to defective insulation of the cells or circuit, or the plates may become short-circuited by particles of the active or foreign substances falling between them.

Sulphating may be removed by carefully scraping the plates. The faulty cells should then be charged at a low rate (about one-half normal) for a long period. In this way, by fully charging and only partially discharging the cells for a number of times, the unhealthy sulphate is gradually eliminated. When the cells are only slightly sulphated, the latter treatment is sufficient without scraping; when the cells are very badly sulphated, the charge should be at about one-quarter the normal rate for three days.

Adding to the electrolyte a small quantity of sodium sulphate, or carbonate, which latter is immediately converted into sodium sulphate, tends to hasten the cure of sulphated plates by decomposing or dissolving the unhealthy sulphate. This is not often used in practice, as a cell must be emptied, thoroughly washed and fresh electrolyte added after the plates have been restored to their proper condition before the cell can be used to advantage.

Sulphating not only reduces the capacity of lead storage batteries, but also uses up the active material by forming a scale which falls off or has to be removed. It also produces the following trouble:

Buckling, or warping of a plate, is caused by uneven action on the two surfaces; for example, a patch of white sulphate on one side of a plate will prevent the action from taking place there, so that the expansion and contraction of the active material on the other side, which occurs in normal working, will cause the plate to buckle. This might be so serious that it would be impossible to straighten the plate without breaking or cracking it; but, if taken in time, it may be accomplished by placing the warped plate between boards, and subjecting it to pressure in a screw or lever press. Striking the plate is objectionable, because it cracks or loosens the active material; but, if it should be necessary to straighten a plate in this way, a wooden mallet should be used very carefully, with flat boards laid under and over the plate. Buckling may be caused by an excessive rate of charging or discharging, as well as by sulphating.

Disintegration. Some of the material may become loosened or entirely separated from the plates, as a result of various causes. The chief of these is sulphating, which forms scales or blisters that are likely to fall off, thus gradually reducing the amount of active material and the capacity of the cell. Buckling also tends to disintegrate the plates. Contraction and expansion of the active material may take place in normal working, and are increased by excessive rates or limits of charging and discharging. This constitutes another cause of disintegration, particularly in plates of the Faure type containing plugs or pellets of lead paste.

The fragments which fall from the plates not only involve a loss of material, but are also likely to extend across or gather between the plates, and causé a short circuit

The positive plates are far more susceptible to and injured by these troubles than the negatives. The former are also more expensive to make, therefore it is to them that special attention should be directed in the management of storage batteries.

Short Circuiting of cell may be caused by conditions preiously stated and also by the collection of sediment at the bottom of the containing cell. The short circuiting caused by the dropping in of foreign matter, or the bridging of the active materials, is prevented by the use of glass, rubber or wooden separators.

The short circuiting of plates by the formation of sediment is prevented, or the chances of it are decreased by raising the plates so that they clear the bottom of the containing cell. In small batteries this clearance is about an inch, in large cells it is considerable, being about 6 inches, and on account of the weight of large sized plates they are supported at the bottom by glass frames running lengthwise through the cell, as shown in Fig. 16.

This sediment should be watched carefully and whên it reaches a depth of 1 inch or more at the center of the cells, it should be removed. The usual method is to take out the plates, syphon the electrölyte off carefully, and then flush out the tanks until all the sediment is removed. If syphoning cannot be resorted to, due to absence of drop, a pump may be used, either of glass or of the bronze rotary type.

Troubles from Acid Spray. An accumulator gives off occasional bubbles of gas at almost any time or condition; but when nearly charged, the evolution becomes more rapid. These bubbles, as they break at the surface, throw minute particles of acid into the air, forming a fine spray which floats about. This spray not only corrodes the metallic connections and fittings in the battery room, but is also very irritating to the throat and lungs, causing an extremely disagreeable cough.

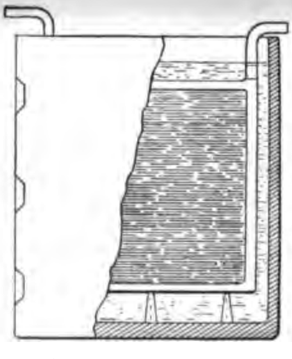


Fig. 16. Glass Frame Support Used to Prevent Short Circuiting by Sediment.

Glass covers are sometimes placed over cells to prevent the escape of fumes, but this is not advisable as the glass becomes moist and will collect dust, thus forming a conducting surface over the cell.

Attempts have been made to do away with this spraying by placing an oil film (thin layer of oil) over the electrolyte, but this has the objection of interfering with hydrometers; in addition it sticks to the surface of the plates when they are removed, and interferes with their conductivity on replacing them.

Another plan consists of spreading a layer of finely granulated cork over the surface of the liquid, but while this does not interfere with the hydrometer, it makes the cell look dirty.

The general practice is to depend almost entirely upon ventilation to get rid of the acid fumes, in fact, even forced ventilation is used. A blower forces fresh air into the room, which is provided with a free exhaust.

In connecting up the cells, it is advisable to use lead-covered copper cables, as this covering protects the copper, and prevents the formation and the dropping of copper salts into the cell.

The Purity of the Electrolyte is very important, and great care should be taken to insure it. The electrolyte may have nitric acid present when "formed" (Planté) plates are used, and some chlorine, when "Chloride" negatives are used. In addition, iron may be present due to the water or acid; if the sulphuric acid is made from iron pyrites; it may also be present, owing to the corrosion of iron fittings near the cells, some of the scale falling into the electrolyte. Similarly some of the copper salt formed from the connections by this corrosive action may fall into the cell. Mercury may also be present due to the breakage of hydrometers or thermometers.

Other foreign substance might be present, but those named are the most harmful.

Nitric acid, even in exceedingly small quantities, will cause disintegration of plates, as the supporting material is destroyed.

Chlorine has a similar effect.

Iron, mercury and copper produce local action, and thus decrease the efficiency and ultimately the life of the cells.

The electrolyte should be tested about once a week for these impurities, and if any of them are present, it should be drawn off and renewed. If nitric acid is present, it is even advisable to flush the cell with pure water.

TESTS.

1. **Test for Chlorine.** To a sample of electrolyte in a test tube, add a few drops of silver nitrate solution; if a curdy white precipitate forms, an excess of ammonia is added, and if this dissolves the precipitate, chlorine is present in some form.

2. **Test for Iron.** Iron may appear in one of two forms, namely, ferrous or ferric salts. A small sample is taken and some concentrated hydrochloric acid added and then some potassium ferric cyanide; if a heavy blue precipitate forms, ferrous iron is present; if in very minute quantities, a deep blue green discoloration results.

3. **Test for Ferric Salts.** To a sample add some ammonium thio cyanate; if a blood red solution or precipitate is the result, ferric iron salts are present.

4. **Test for Copper.** To a sample of electrolyte an excess of ammonium hydrate is added; if a rich blue solution is the result, copper is present. It is advisable to check the test by taking another sample and adding some potassium hydrate to it; if a blue precipitate is found which turns black upon boiling, it is additional proof of the presence of copper.

5. **Nitric Acid** being injurious even in very small quantities, it is advisable to make the following test, which is very sensitive. Some diphenylamine in concentrated sulphuric acid is added to the sample; if a deep blue color is the result, nitrates or nitrites are present.

6. **Test for Mercury.** Mercury may be present in two forms, mercurous or mercuric compounds. The *mercurous* compounds give a black precipitate with lime water, and a greenish precipitate with potassium iodide.

The *mercuric* compounds give a yellow precipitate with lime water, and a red or scarlet precipitate with potassium iodide.

On account of possible difficulties with these various impurities the following is recommended:

1. Test every carboy of sulphuric acid before using.

2. Concentrated sulphuric acid should not be kept around, as it may be used by mistake, which would ruin the plates.

3. Only distilled water from carboys should be used and not from barrels, as it may be contaminated from the organic material of the barrels.

4. Water from the city mains is never to be used unless the amount of impurities which it contains is very small.

5. When testing with hydrometer for specific gravity, the battery should be fully charged and the temperature constant.

Quantitive tests are generally necessary.

Putting the Battery out of Commission. If, for any reason, the battery is to be but occasionally used, or the discharge is to be at a very low rate, a weekly freshening charge to full capacity at normal rate should be given.

It frequently happens in practice that a storage battery equipment is put out of commission for a lengthy period, (for instance, in most summer or winter resorts the battery may be used for one half of the year only). In such cases the procedure is as follows: First give the battery a complete charge at normal rate, then syphon off the electrolyte into carefully cleaned carboys (as it may be used again), and as each cell is emptied, immediately refill it with pure water. When the acid has been drawn from all cells and replaced with water, begin discharging the battery and continue until the voltage falls to or below one volt per cell at normal load (rate); when this point has been reached the water should be drawn off. In this condition the battery may stand without further attention until it is to be again put into service, and to do this proceed in the same manner as when the battery was originally put into use.

If during the discharge, when the water has replaced the electrolyte, the battery shows a tendency to get hot (100°F,) add colder water.

Commercial Application. The function of a storage battery is to receive electrical energy at one time or place, and to give it out at some other time or place.

The principal uses are the following:

1. To furnish portable electrical apparatus with power.

2. To make up for fluctuations, and thus steady the voltage and load on the generator.

3. To furnish energy during certain hours of the day or night, and enable the generating machinery to be stopped.

4. To aid the generating plant in carrying the maximum load (peak) which usually exists for only an hour or two.

5. To make the load on engines or prime movers more uniform, by charging the battery when the load is light.

6. To transform from a higher to a lower potential by charging the cells in series, and discharging them in parallel, or vice-versa.

7. To subdivide the voltage, and enable a three or a five wire system to be operated from a single generator.

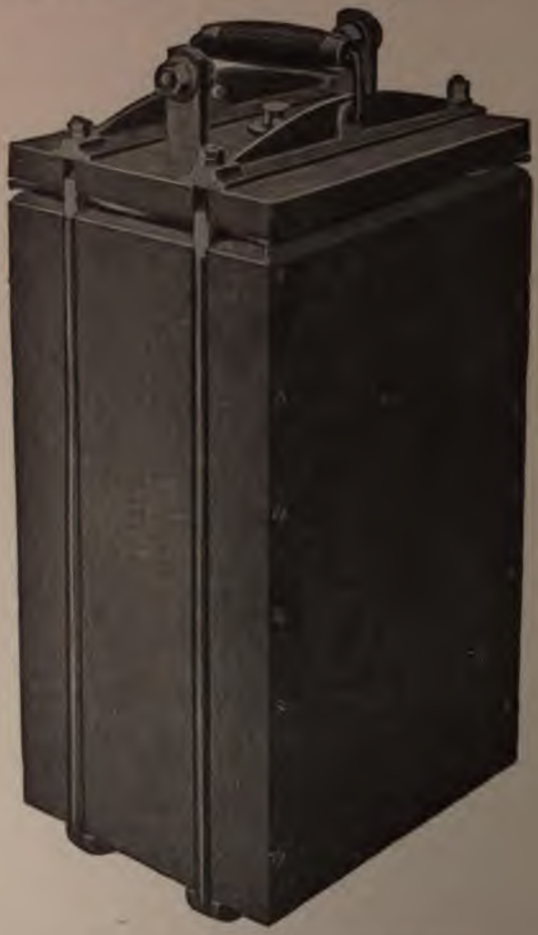


Fig. 17. Gould Portable Storage Battery.

8. To supply current from local centers or substations.

9. To supply current to electrically driven vehicles.

10. As sources of current in telephone and telegraph systems.

11. For car lighting purposes.

12. As sources of constant potential and current in electrical laboratories.

Portable Storage Batteries. The storage battery is practically the only means of supply for portable electric lamps, or those not connected to a dynamo even when they are not portable. The primary battery is expensive and troublesome to operate; and has never been commercially successful for electric lighting or power, except where only a very small amount is required. Nor is there any other satisfactory primary source of electrical energy except the dynamo driven by mechanical power. It is therefore practically essential to adopt storage batteries wherever portable electric motors, lamps, etc., are used.

The various manufacturers furnish portable forms of storage batteries: for example, the Gould Storage Battery Company's portable battery (Fig. 17) is arranged in a case made as a hard rubber jar, lead-lined box or glazed earthenware jar, over which is placed a rubber gasket, and then a wooden cover clamped in place by U shaped straps, passing around the containing vessel. For ventilation in charging, the cover has threaded holes which, when the battery is in use, are closed with hard rubber stoppers. The usual number of cells in a case is from one to five, although they are made up in larger numbers if desired. The batteries are rated at 2 volts per cell.

A serious objection to portable storage batteries is their great weight. For example, a standard size weighing 60 lbs. yields 5 amperes at ten volts, or fifty watts for ten hours: just enough to feed a 16 C. P. lamp. The total discharge is 500 watts-hours or two thirds of one H. P.-hour. The special forms of battery used in automobiles give about twice this output for the same weight.

This weight is almost prohibitive to portability except for automobiles, railway train lighting and special purposes.

Portable batteries, for example, are used for feeding small motors, lamps etc. for medical or dental purposes, in which cases their weight is not a serious difficulty in view of the importance of the work, and the small amount of energy required. Another special field for very small batteries is the theatrical application for which they are carried by the performers. Storage batteries are also being extensively used as source of power to drive small fan and kinetoscope motors.

Storage Batteries for Preventing Fluctuations due to unsteadiness in the driving-power or in the load, as with elevators, are often applied successfully. A dynamo driven by a gas-engine, for example, may vary periodically in speed because of the explosive action of the gas in the cylinder; and a battery connected in parallel with the dynamo will have the effect of steadying the voltage. A storage battery is generally installed in connection with a small gas or steam engine lighting plant to enable the engine to be stopped for a considerable portion of the time, and thus save labor and attention, in which case the battery may also act to prevent fluctuations. A windmill electric-lighting plant must have an accumulator or some other means of storing energy, not only to eliminate fluctuations in speed which are continually occurring, but also to bridge over the considerable periods of calm weather.

To Furnish Energy During Certain Portions of the Day or Night. In almost every electric-lighting plant, there are long periods during the day and late at night when the number of lamps lighted is so small that it may not pay to run the generating machinery.

For example, Fig. 18 is a load diagram showing the weekly output of the electric plant of the Astor Building in New York City. The generator plant runs from 3 A.M. to 8 P.M. each day, the battery being charged from 3 A.M. to 11 A.M.; and when the generating plant is shut down at 8 P.M. the battery carries the entire load from then until 3 A.M., when the plant is started up again. Saturday nights the plant is shut down at eight o'clock, and the battery furnishes all the power required from then until Monday morning at 3. This enables the plant to be operated by two gangs or shifts; practically no labor being required for the remaining seven hours as the battery carries the load, and the machinery is stopped entirely all day Sunday, giving a stretch of thirty-one hours once a week and seven hours each night for cleaning and repairs. In a hotel, residence or on board a yacht, it may be desirable to stop the machinery and avoid the vibration and noise during the night.

Storage Batteries to Aid in Carrying the Maximum Load. Assume in the case of the load diagram shown in Fig. 19, that the generating machinery is capable of supplying 8,000 kilowatts and that a storage battery is used to furnish the remaining 3,600 kilowatts at the time of maximum load, that is, the "peak" of the load diagram. This simply means that batteries are substituted for a certain portion of the machinery plant, and the question is whether or not the substitution is of any advantage.

The first cost of a battery for a given rate of output depends simply upon the time of discharge. Batteries usually have a normal period of discharge of about 8 hours, at which rate the price of accumulators to furnish a given number of watts would be 3 to 5 times as great as that of the equivalent boilers, engines and dynamos combined, but if the time of discharge is reduced to about 2 or 3 hours, the costs are about equal and with a still higher rate the cost of batteries would be less.

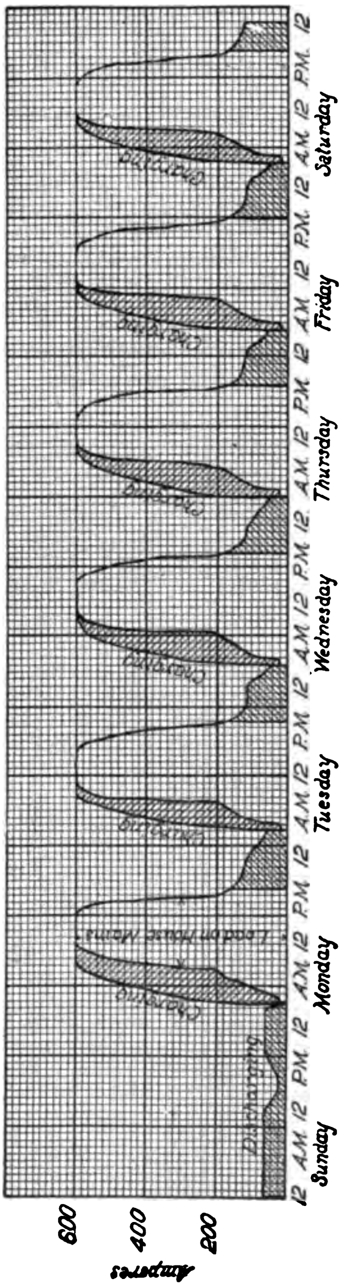


Fig. 18. Load Curve of Astor Court Building.

As a matter of fact, the storage battery secures other advantages so that the total gain may be very important. For example, there is a reserve supply in case of accident and the load may be made more uniform as will now be explained.

Storage Batteries to Maintain Uniform Load on Engines. Steam engines are very inefficient at light loads, and this fact often causes serious losses especially in electric-lighting plants. Judicious selection of the number and sizes of the engines enable them to be worked in most cases at a considerable fraction of their full capacity nearly all of the time. Nevertheless, the storage battery gives greater flexibility to the plant, and renders it easy to increase the economy of the engines by making their loads still more uniform, and nearer to their full capacities while they are running. The engines can be made to have a uniform full load, the battery being charged when the external load is light, and the battery taking the peak of the load when it is heavy.

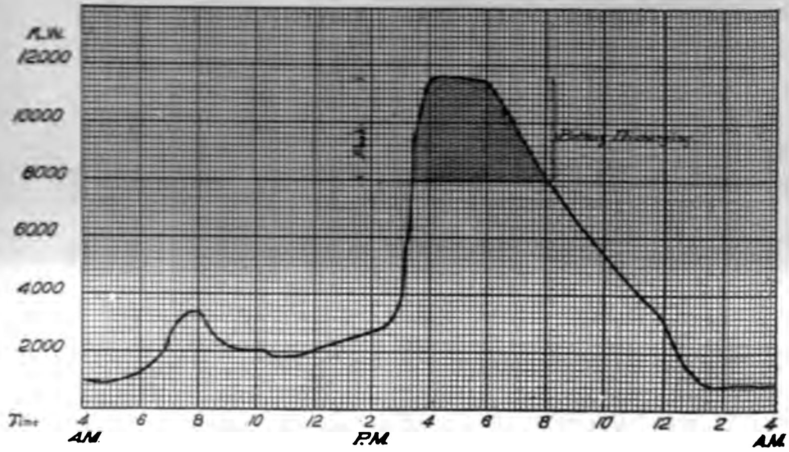


Fig. 19. Load Curve Showing "Peak" of Load Carried by Storage Battery.

Storage Batteries Used as Transformers. If the cells of a battery are arranged in series while being charged, and in parallel for discharging, a high voltage will be required for charging, and a low voltage will be given out. The amounts of energy measured in watt hours are the same, less the loss of about 25 per cent which always occurs in accumulators; the result is similar to that obtained by an alternating current transformer or motor-dynamo but is less efficient. As an example the equipment used at the Brooklyn Navy Yard may be mentioned. It consists of about 250 small cells connected up in series parallel of 5 sets of 50 cells each and charged on a 110 volt circuit. When discharged they are connected up all in series and give about 500 volts but with very small current. This equipment is used to furnish 500 volts for the "insulation test" of cables and therefore requires little or no current.

Storage Batteries Used for Subdividing Voltage. The most important practical case is that in which a dynamo of 220 volts charges a battery of corresponding potential, a three wire system being supplied from the battery, the neutral wire of which is connected to the middle point of the battery as represented in Fig. 20. This arrangement avoids the necessity of running two dynamos, and allows the battery to be placed in a sub-station near the district to be supplied, so that it is only necessary to run two conductors to that point instead of three. The same principle may be applied to the five-wire system.

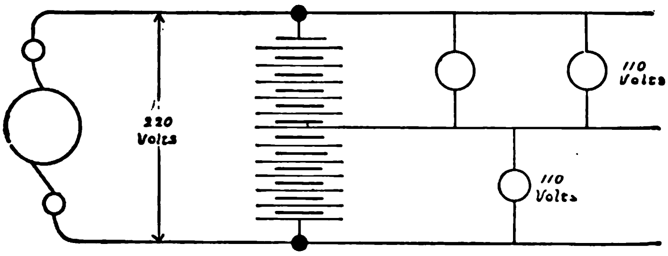


Fig. 20. Battery used to Sub-divide Voltage.

The Hartford Electric Light Company was one of the first in this country to introduce the modern method of high tension transmission, with low-tension 3 wire distribution.

The auxiliary battery used in connection with this equipment consists of 130 Chloride Accumulators (65 on a side) each cell containing 31 negatives and 30 positive plates, each 15½" x 31", placed in lead-lined tanks measuring 58¼ x 21½ x 43⅞ inches. Fig. 21 is a diagram showing the general plan of the system. The power is transmitted 10.8 miles from the Farmington River

Power Station to the Pearl Street Station, in Hartford, by means of step-up transformers, a ten thousand volt transmission line, and step-down transformers for distribution. From Pearl Street Station to State Street, a distance of three thousand feet, the current is transmitted at twenty-four hundred volts, at which latter point, by means of step-down transformers and rotary converter, the storage battery is charged and the current distributed over a low tension three wire system.

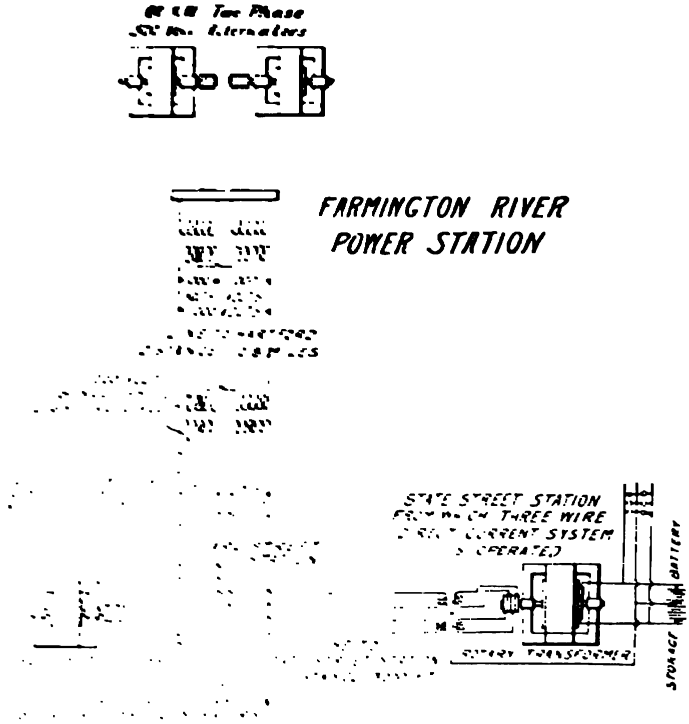
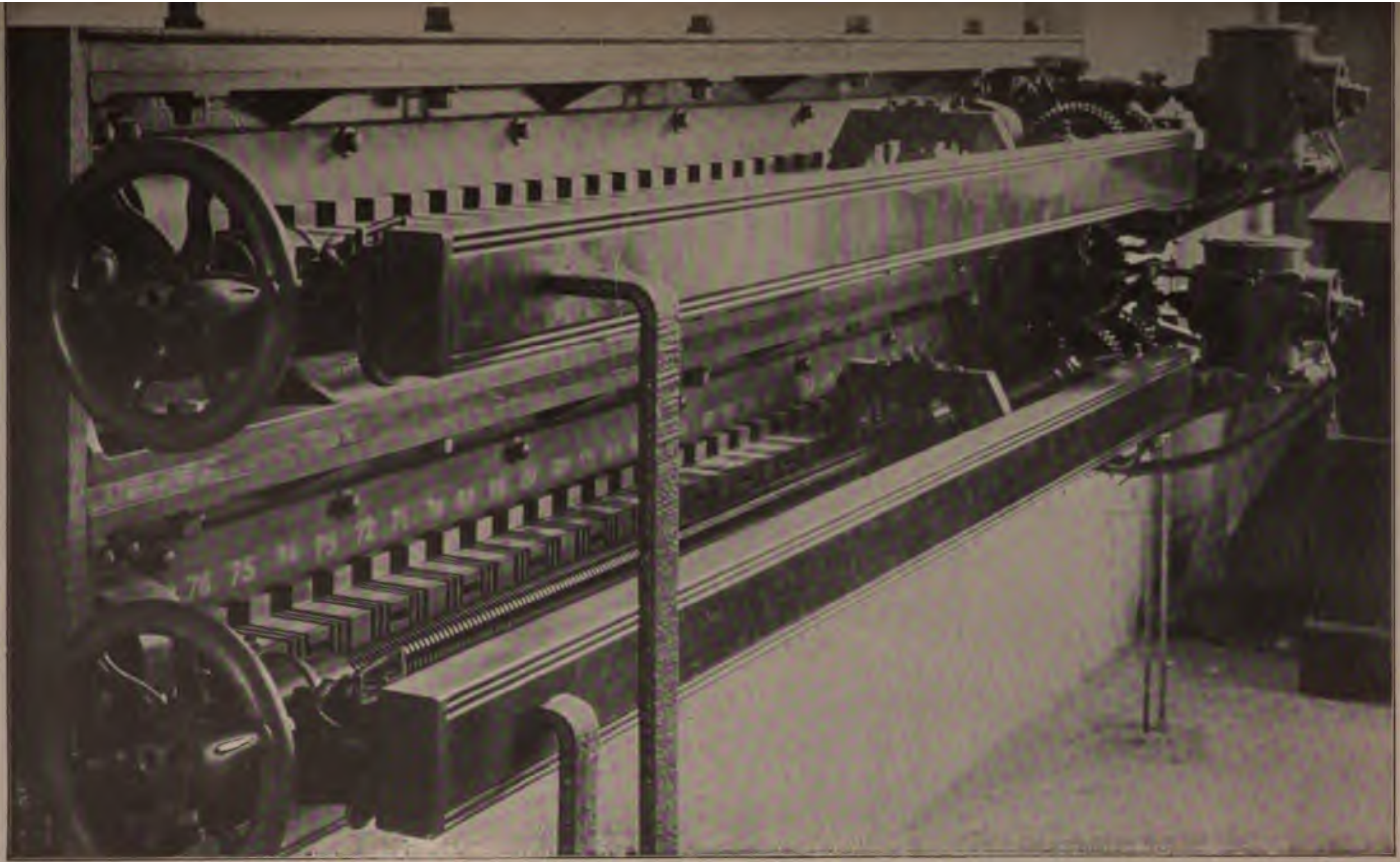


Fig. 21. Plan of the Farmington River — Hartford Distribution System.

Storage Battery for Sub-Stations. The plan of installing battery plants at local centers, which are charged from the main station, enables some of the conductors to be saved in a three (or five) wire system, as already stated. It also makes it possible to reduce the size of these conductors, because the current which flows over them can be kept practically constant, so that it is not necessary to have them large enough to carry the maximum cur-



End Cell Regulating Switches

Minneapolis General Electric Company

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ASTOR, LENOX
TILDEN FOUNDATIONS

rent consumed by the lamps, etc. which may be several times its average value. The generating machinery has the same steady load as if the battery were located near it.

The batteries at the various sub-stations may be connected and charged in series or in parallel. The former plan would require far less copper in the conductors since the voltage is multiplied by the number of batteries in series, and the current is the same as for a single battery. On the other hand, this great difference of potential would exist between the first and the last batteries of the series and if either of these became grounded, any person connected to the earth and touching a wire supplied by the other battery would receive a shock due to the total voltage.

An excellent example of the storage battery sub-station is the Bowling Green Plant of the New York Edison Company the description of which is as follows: The Bowling Green Station furnishes an auxiliary supply of current directly from the battery, enabling the feeders, extended as tie feeders into the Bowling Green building, to be used as distributing feeders to the system from both the Duane Street and Bowling Green Stations. While acting as an auxiliary supply to the general system, the battery also takes care of the distribution of current to the extensive installation in the Bowling Green Building itself. The supply of current to charge the battery is taken from the Duane Street Station, about a mile distant, over four tie feeders equipped with controllable disconnective switch boxes on the Bowker-Van Vleck system. This enables them to be used as tie feeders by disconnecting them from the general system during the hours of light load, and as distributing-feeders during the hours of maximum load, when they feed current into the system from each end. A considerable saving is thus effected in the investment because costly feeders are not required to supply the maximum load to a distant part of the system.

This installation of an auxiliary source of current supply in the lower district makes it possible to shut down the generators in the Duane Street Station during the hours of minimum load, the supply of current to the district below 8th Street being derived from the battery plants at Bowling Green and 12th Street Stations, supplemented, if desired, by the supply of current from the 26th Street Station over the tie lines to 12th Street Station, whence the current is distributed through boosters raising it to the required potential, over the tie feeders to the Duane Street Station switch board. The battery and operating rooms of the Bowling Green Station are located in the sub-basement of the Bowling Green Office Building. Vitrified hollow tile for conducting the feeder cables are laid under the battery room floor, which consists of glazed white tile. Drains to carry off the water or acid run in the aisles between the cells and lead to small cesspools which discharge into a lead drain pipe.

The battery consists of 150 Chloride cells, seventy-five in series on each side of the three wire system. The cells consist of wooden tanks, 40¾ by 21½ by 30½ inches, treated with an acid proof paint and lead lined, each containing 14 positive and 15 negative plates 15½ inches wide by 31 inches high. Each tank is supported on four petticoat porcelain insulators resting upon 6-inch glazed tiles.

The plates are suspended in the tanks by shoulders resting upon sheets of heavy glass, which stand upon lead saddles in the bottoms of the tanks. The cells are connected by welding the plate terminals to lead bus bars, no mechanical connections being used.

Twenty of the end cells on each side of the system are used for regulating; being separately connected to contact points on the regulating switches, which carry movable contacts operated by a screw. The potential is raised or lowered by cutting in or cutting out the regulating cells. Two regulating switches are connected in multiple on the positive and two on the negative sides to permit of discharge at two potentials, or to enable the battery to be charged and discharged simultaneously. The conductors between each series of cells, and between the regulating cells and the regulating switches, consist of copper bars 3 inches wide by ½ inch thick. These bars are supported on porcelain insulators resting in hangers.

The connections of this equipment are shown in Fig. 22.

The capacities of the battery at various rates of discharge are:

2000 amperes per side for 1 hour.
1000 amperes per side for 3 hours.
400 amperes per side for 8 hours.

Provision has been made in the battery-room for the installation of a duplicate battery, which can be placed over the present plant. The booster is used to raise the voltage from that of the system to that required for charging the battery. The booster can be used also to raise the voltage of discharge for feeding some distant point of the system at a higher potential than would be normally required. The machine consists of one positive and one negative dynamo at each end of a common shaft driven by two motors. Each dynamo has a capacity of 1200 amperes and a range of pressure up to 60 volts.

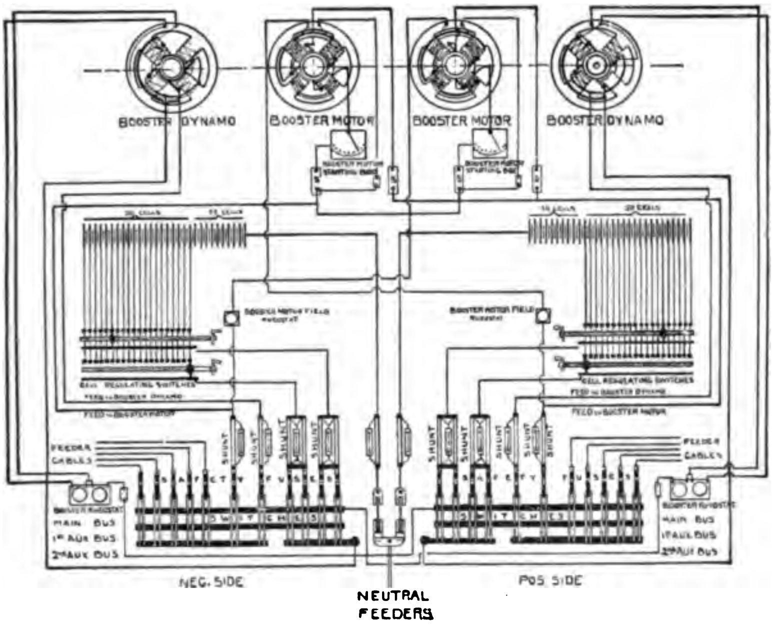

Fig. 22. Connections of the Bowling Green Storage Battery Sub-station.

Storage Batteries Used for Two or More of the Above-named Purposes. Each of the different uses has been considered separately to avoid confusion, but in most cases the storage battery is adopted in order to secure several advantages. By thus combining different applications the plant is rendered not only more economical, but also more flexible. For example, the battery may be utilized to help out the generating machinery at times of heavy load, or when the latter is partially or wholly disabled. It often happens that it is difficult to produce or maintain sufficient steam-pressure, owing to poor draft or other conditions, in which event a battery enables the boilers to be temporarily relieved of some or all of the drain upon them while the pressure is being raised to the proper point. It may also be necessary or desirable to shut down the machinery or a portion of it, temporarily, in order to make some repair or adjustment. It is also possible to feed some of the circuits from the battery while the others may be supplied at a higher or lower voltage by the machinery. In these and many other ways the storage battery may be a convenient adjunct to an electrical system. The fact that it is so radically different from the machinery in its nature and action makes it very unlikely that the entire plant will be crippled at any one time, since the two sources of current are not exposed to the same dangers. An accident to the steam-piping, for instance, might shut down all the machinery, but probably it would not affect the battery; and, vice-versa, an accident to the latter is not likely to extend to the former.

As an example of this application of the storage battery to several purposes, the following case may be cited:

The installation of storage batteries at the power house of the Woronoco Street Railway Company, in Westfield, Mass., presents features of special interest. After considering various methods of increasing the power-house capacity, rendered necessary by the construction of an extension of the line, it was decided that the storage battery offered the greatest advantages.

The station equipment consists of two 75-KW. multipolar generators belted to two 120 H.P. high-speed, simple, non-condensing engines, steam being furnished by two 90 H.P. return tubular boilers.

The battery consists of 264 cells of the "Chloride Accumulator," Type F-11, in glass jars of Type F-13, permitting an increase of 20 per cent by the addition of one pair of plates in each cell, and is installed in a small brick extension to the power house. The cells are located in one tier, each cell being supported on a sand tray resting on four glass insulators. The foundation for each row of cells consists of two stringers of wood suitably braced and supported on brick piers. This battery was not installed as a voltage regulator, the feeder system being so designed that the drop on the line is only a small amount.

By means of the battery the load on the machinery is reduced within the capacity of one unit, leaving the second one as a reserve in case of an accident or an unusually heavy load. Without the battery both machines would be needed nearly all the time.

The economy of operation, due to using one unit instead of two, is clearly shown by the following station records.

	Date, 1899.	Lbs. coal.	Output kw.-hrs.	Lbs. coal. per kw.-hr.
With battery	Oct. 25-27	16,250	3,032	5.36
Without battery	Oct. 28	6,250	981	6.37

This shows an increase in the coal consumption of 19 per cent. on the day when the operation of the battery was discontinued. The plant is also noteworthy from the fact that the station attendance is reduced to one man per shift, the engineer doing his own firing. This arrangement could not have been continued under the conditions of increased load, had it not been for the improved regulation and reduction of coal handling, and especially the increased reliability of operation secured by the battery.

On several occasions the battery has been called upon to carry the entire load of the system for an hour or so, during a temporary shut-down of the rest of the plant, as well as early in the morning or late at night, when only one or two cars are in operation.

Storage Batteries for Propelling Vehicles and Boats. The storage battery is usually about 35 per cent of the total weight in the modern electric automobile, and even with this great proportion, the distance run on one charge is seldom more than from 20 to 40 miles at a speed of about ten miles per hour, and that only on comparatively smooth roads. The battery equipment varies in different types of vehicle, but is generally 24, 36, or 44 cells and of a capacity in proportion to the size of the vehicle.

In cities or where the roads are good, with charging stations close at hand, the electric automobile is superior to the gasoline types, on account of the absence of explosive vapors, with the accompanying odor and noise. But for general touring they are not as handy on account of the limited capacity of the battery.

The application of the storage battery to the street car, while presenting such great advantages as the entire absence of poles and overhead wires, has not been a commercial success, mainly on account of the mechanical weakness of the plates, which are not able to stand the jolting and jarring or the rush of current due to frequent starts and stops. Another objectionable feature was the escape of acid fumes into the car, producing throat irritations and coughs among the passengers, although this was overcome by the use of fans.

The storage battery has been comparatively successful as a source of power in submarine boats, being charged while the vessel is on the surface, and discharged to run electric motors and lights when the vessel is manœuvering under the surface.

Storage Batteries in Telephone and Telegraph Systems. Since the adoption of the central battery systems by telephone companies, the use of the storage battery for this purpose has become very common, its advantages over the primary cell being as follows: Lower first cost, smaller space required (about $\frac{1}{4}$ of that occupied by an equivalent primary battery), greater constancy of E. M. F. and lower internal resistance, absence of the annoying "creeping salts," and rapidity of recharge. The cost of storage battery maintenance is about $\frac{1}{8}$ that of the primary cell.

In telephone work, the battery is installed in the district station, and charged when the line is not in use, from either a street connection or a generator in the station. When the line is in use for conversation, the charging current is automatically cut off, and the battery alone switched into service.

The storage battery in telephone work has become so important that the following description of a typical installation is given.

In the Filbert Street Exchange of the Philadelphia Bell Telephone Company there are two generating units, forming a duplicate plant, each consisting of one engine, directly connected to a 30 K. W., 110 volt dynamo. These machines are run on alternate days and are used for lighting the building and for furnishing power at 110 volts to various motor generators. The latter comprise two 1.5 K. W. machines for charging a 20-volt battery, one 1.5 K. W. machine for charging an 8-volt battery; one 500-watt machine for charging a 4-volt battery, and two $\frac{1}{4}$ H. P. 75-volt alternating current motor-dynamos for ringing call bells. Only one machine is installed for the 8-volt battery and one for the 4-volt battery. Both batteries are in duplicate. To avoid a possible break down, a rheostat is furnished, so that the batteries of lower voltage can be charged from batteries or motor-generators of higher voltage. All machines are protected by automatic cut-outs.

The 20-volt battery consists of ten "Chloride Accumulators" having a capacity of about 1,000 ampere-hours, which furnish all the current needed by the subscribers for talking and for calling up the central office. The 8-volt batteries, in duplicate, consist of four cells each having a capacity of 2,400 ampere-hours. This battery furnishes current for the "disconnect" signals on the operator's cords, and for the relays which cut out the subscriber's lamp signal when the operator answers his call, by plugging into the jack corresponding to the lamp signal.

Half the drop in potential of the 8-volt battery is in the 4-volt lamp, and the other half in the cut-out relay. This battery is in duplicate, so that one can be charged while the other is being discharged. This avoids danger of burning out the lamps, as the voltage of the battery is raised from 8 to 10 volts during charging.

Each of the duplicate 4-volt batteries comprises six 13-cells arranged in two sets. One of these sets consists of four cells, two in series, two in multiple; the other of two cells. The two extra cells are needed on one of the batteries to supply current for the operator's transmitters. The latter is arranged to furnish a current of four volts or two volts as desired. The 4-volt battery also furnishes all current for the lamp signals which light when a subscriber takes his telephone off the hook. This lamp is put out when the operator answers the call. This battery also is made in duplicate, one being charged while the other is discharged, to avoid burning out the lamp from the higher voltage during charge.

Storage Batteries for Train Illumination. When cars are lighted by oil or gas lamps, these, owing to their size, and the heat produced by them, can be installed only in certain places, so that the distribution of light is not general, besides which, the heat and odor given off by the lamps are objectionable. The inflammable character of the illuminants involves great danger of explosion or fire in case of a train wreck. The absence of these disagreeable and dangerous features in electric lighting, is what has made its application so desirable in traction work.

Several methods of electric illumination have been tried on railroad trains. In one of the simplest of these a small dynamo, on the locomotive truck, or one perched above the boiler, is driven by a small steam turbine. While this is an economical method, it has the objection, that when the locomotive is uncoupled, the cars must be illuminated by some other means.

For this reason, the storage battery system of supply has been adopted. A description of one of tne most successful meth-

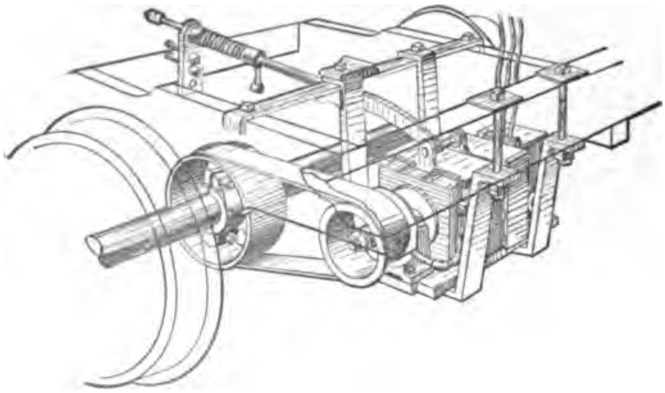

Fig. 23. Method of Suspension Used by the "Axle Light" System.

ods is as follows: The "Axle Light" System, as its name implies, derives the motive power for its dynamo from the car axle. The mechanism is suspended from the bottom of the car, and is completely encased, so as to be dust and water proof. It comprises a small dynamo driven from a pulley on the axle of the car by means of a friction coupling.

The dynamo and driving mechanism are shown in Fig. 23. The former generates from 32-40 volts, depending upon the speed of the train provided that it exceeds 15 miles per hour, the dynamo being then automatically connected to the battery and lamp circuit. An automatic device rectifies the direction of current, so that even though the direction of rotation is reversed, the battery is always charged in the proper direction. A variable resistance in series with the field coils is automatically adjusted by a small motor, so that even at high speed the normal limit of voltage is not exceeded.

The lamps are 16 C. P. at 30 volts, the filaments being short and heavy so that they are not injured by vibration.

After the storage battery has been charged, it acts in parallel with the dynamo and avoids fluctuations in voltage. When the car stops, the dynamo is automatically cut out and the full supply of current is furnished by the battery, which is large enough for a ten-hour supply at full load.

Storage Batteries for Electrical Laboratories. The great advantage of this source of power in electrical laboratories, is the fact that any variation in the voltage is very gradual, and by the simple regulation of a rheostat in series with the battery, the operator can keep his voltage and current absolutely constant, while a test or calibration is being made. When a large current is wanted, as in the case of ammeter calibration, the cells may be connected in parallel, and discharged through a low resistance, thus cutting down the energy required for the test. A storage battery may also be used to step up the voltage, the cells being connected in parallel groups for charging and in series for discharging.

Connection and Regulation of Storage Batteries. The complete control of a battery in an electric-lighting plant requires provision to be made for feeding the lamps, etc., from either the dynamo or battery separately, or from the two working in parallel; and it should be possible to charge the battery at the same time that lamps are being supplied. To accomplish these results requires three switches,— one to connect the battery to the dynamo, one to connect the lamps to the dynamo and one to connect the lamps to the battery. In some plants the second switch is omitted, because the lamps are always fed by the battery alone, the latter being charged during the day, when no lamps are in use. However, it would seem desirable to have all three switches in every plant in order to be able, at least, to supply lamps and charge the battery at any time. In the battery circuit there should be an amperemeter having a scale on both sides of zero, so that it shows whether the battery is being charged or discharged, as well as the value of the current. Another amperemeter is required in the circuit between the dynamo and the battery, to show the direction and amount of current. A third amperemeter is desirable in the lamp circuit, to show the total current supplied to the lamps; but it need only indicate on one side of zero, since the current there always flows in the same direction. A voltmeter is required with a three-way switch, which enables it to be connected to the dynamo, battery, or lamps respectively.

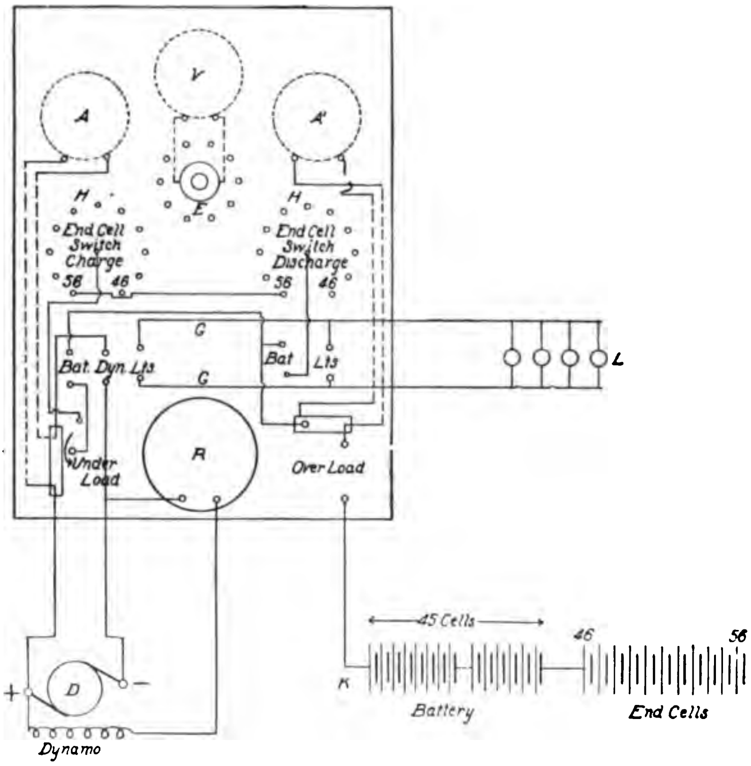

Fig. 24. Switchboard, Dynamo and Battery Connections.

An automatic overload switch must be inserted in the battery circuit so as to open or introduce resistance into the circuit when the current becomes excessive. An automatic cut-out is required between the dynamo and the battery to open the circuit when the charging current falls below a certain value, and thus avoid any danger of the battery discharging through the dynamo, if from any cause the E.M.F. of the latter drops below that of the former. This completes the ordinary measuring and circuit-controlling apparatus employed in connection with storage batteries. The arrangement is shown diagrammatically in Fig. 24, in which A and A^1 are the two amperemeters, the third one being omitted in this case; V is the voltmeter; E the voltmeter switch to connect to the dynamo, battery, or lamps as desired; G the bus bars; L, lamps; D, dynamo; R, rheostat in field-circuit of dynamo.

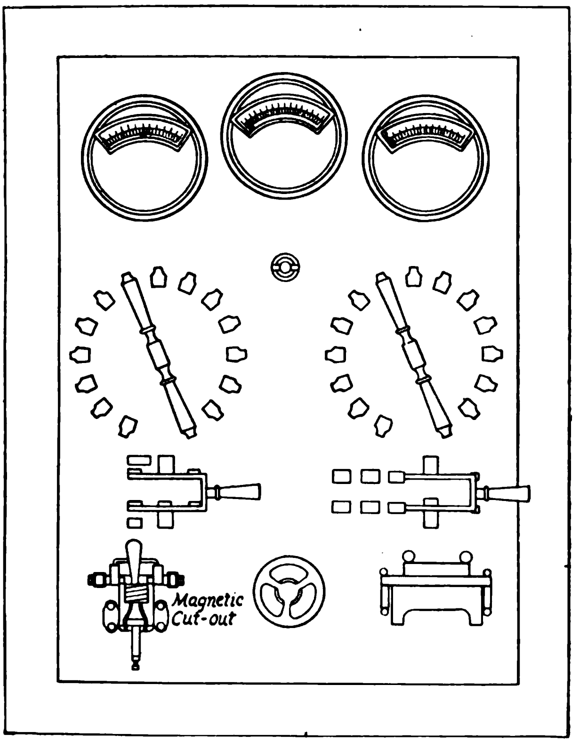

Fig. 25. Face of Switchboard.

The regulating device consists of eleven end cells, which are connected to corresponding contacts on the end cell switches (Fig. 24). But as the drawing of these connections would complicate the figure, they have been omitted. Fig. 25 shows the switchboard with these devices mounted upon it.

The Regulation of Storage Batteries is one of the most troublesome matters involved in their practical use. This arises from the fact that the voltage falls continually from the beginning to the end of discharge. To be sure, this decline is gradual; but its total value is large, being from about 2.2 to about 1.8 volts, which is a decrease of nearly 18 per cent.

In order to maintain a constant voltage, the usual plan is to have a number of extra cells, which are successively switched into circuit as the potential falls. These reserve cells and the switches which control them are represented in Fig. 24.

The contact pieces of these switches must be made in such a way that they do not short-circuit the cells as they pass from one point to the next. This is accomplished by splitting the movable contact arm into two parts, between which a certain amount of resistance is introduced, so that when the two parts happen to rest on two adjacent contact points, the resistance prevents the cell which is connected to these two points from being short-circuited, and also avoids breaking the circuit.

The number of extra cells depends upon the conditions; for 110 volt lamps, it would require 51 cells to obtain 112.2 volts when fully charged and giving 2.2 volts each, assuming the drop on the conductors at 2 per cent. When the battery becomes discharged, and its potential falls to 1.8 volts per element, 10 additional cells or 61 in all, would be needed. These would yield 111.8 volts, assuming the average potential of the reserve cells to be 2 volts, since they have not been discharged to the same extent as the original battery. If the drop on the conductors is 10 per cent of the lamp voltage, the potential at the battery will have to be 110 + 11 = 121. This will necessitate 4 more elements, or a total of 65 when the 51 original cells are fully discharged to 1.8 volts, and the 14 extra cells give 2 volts each.

For a three wire system the above figures should, of course, be doubled. This switching of extra cells into and out of the circuit obviously results in discharging them unequally, hence they require to be charged to a corresponding extent. This is accomplished by successively cutting the cells out of circuit as soon as they become fully charged, the last cell which was put into the circuit being fully charged in the shortest time, and so on. The amount of charge is determined by the methods already given. If the cells employed are not injured by overcharging, they may be left in circuit until the entire battery is fully charged. This saves the trouble of operating the switch; but it is wasteful of energy, since the full counter E. M. F and resistance of the charged cells must be overcome, which requires about 2.5 volts more per element. The switches might be operated automatically by a voltage regulator or by clockwork.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

DIRECT CURRENT DYNAMOS.

1. Explain briefly the two different methods of distributing electrical power.

2. (*a*) Why does the series characteristic curve bend over and the voltage begin to decrease when the current is large? (*b*) Explain why the E. M. F. of a series dynamo decreases very rapidly from about two-thirds its maximum value upon decreasing the current. (*c*) Draw a diagram of the circuit of a series dynamo.

3. (*a*) Why is the voltage of a shunt dynamo at its maximum an open circuit? (*b*) Why does the voltage of a shunt dynamo decrease when the load is increased? (*c*) Draw a diagram of the circuit of a shunt dynamo.

4. (*a*) What is the general form of the characteristic of a compound dynamo? (*b*) What is the difference between a long shunt compound-wound dynamo and a short shunt compound-wound dynamo? (*c*) Draw a diagram of the circuit of a short shunt compound machine.

5. What values of E. M. F. and current are used in plotting the external, internal and total characteristics of the shunt dynamo?

6. How does the construction of shunt coils differ from that of series coils?

7. (*a*) Why does sparking occur if the position of the brushes is such that the short-circuited coils generate no E. M. F.? (*b*) What is the correct position of the brushes for sparkless running?

8. Why should not the current pass through the springs which are used to give the brushes proper pressure upon the commutator?

REVIEW QUESTIONS

ON THE SUBJECT OF

DIRECT CURRENT MOTORS.

---

1. State briefly the fundamental principle of a motor.

2. Upon what does the speed of a motor depend?

3. The armature resistance of a motor is .6 ohm and the E. M. F. applied at the brushes is 120 volts. When the counter E. M. F. is 82 volts, what current passes in the armature?

Ans. 63.+ amperes.

4. Explain why the speed of a series motor on a constant potential circuit increases when the load is removed.

5. What are the different ways of reversing the direction of rotation of motors?

6. If the output of a motor is 60 horse-power and the armature makes 490 revolutions per minute, what is the torque?

Ans. 643.+ foot-pounds.

7. Why is it necessary to cut out the starting resistance of a motor in order that it may be brought up to speed?

8. In what direction will the armature of a shunt generator rotate when run as a motor compared with the direction of rotation when run as a generator? Explain.

9. Explain briefly the different methods used to vary the speed of shunt motors.

10. A shunt motor on a 230 volt circuit takes 55 amperes at full load, the speed being 750 revolutions per minute. What resistance is it necessary to insert in the armature circuit in order to have the motor run at $\frac{2}{3}$ speed when the torque is $\frac{1}{2}$ that at full load?

Ans. 2.8 ohms (approx.).

11. In stopping a shunt motor why should the main switch be opened before the armature circuit is broken?

12. What are the advantages and disadvantages of series motors?

13. The current in the armature of a shunt motor is 30 amperes and the E. M. F. at the brushes is 220 volts. If the armature resistance is .8 ohm, what is the counter E. M. F.? Ans. 196 volts.

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART I.

---

1. Why is the steam turbine well adapted for direct connection?

2. On a three-wire system is it better to use 110-volt or 220-volt motors ? Explain why.

3. Describe construction and operation of the Fort Wayne self-starting synchronous motor.

4. What methods are used for controlling the speed of induction motors ? Which one is preferable ?

5. How can the friction of brushes and bearings be tested roughly ?

6. What points should be considered in the selection of a machine ?

7. Give a sketch of the connections of a compound-wound motor.

8. What is the advantage of a synchronous motor when its field is over excited ? Explain.

9. Give a safe rule to follow for personal protection when handling electrical circuits of a sufficiently high voltage to be dangerous.

10. What precautions must be taken in fixing a direct-connected set ?

11. Why should starting boxes always be furnished with direct-current motors ?

12. (a) How are small induction motors started ? (b) Why cannot large sizes be started in the same way ?

13. If a machine is to be taken apart for the purpose of cleaning or inspecting it, what precautions should be taken ?

14. Describe the method of lacing a belt.

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC WIRING.

---

1. Under what conditions is "fishing" of wires allowed? Explain the process.

2. In conduit work how many quarter bends are allowed from outlet to outlet?

3. Tell what you can about flexible cord.

4. Where should cut-outs or circuit breakers be located for house wiring?

5. What must be the voltage of the dynamo in order to supply [illegible] in a 110-volt system, with a 5 per cent loss?

6. What is a [illegible] pole?

7. When a high potential machine has its frame grounded, what precautions should be taken for the protection of the attendant?

8. What can you say about the rules to be followed when installing wires?

9. Give a rule for the proper depth to which to set a pole.

10. How would you ground a dynamo frame?

11. What is the least allowable radius of curvature in conduit work?

12. State the rule to be followed in starting or stopping motors.

13. What is the objection to putting the ground wire from a lightning arrester into an iron pipe?

14. State briefly the requirements for interior wiring in the case of series arc lighting work.

GENERAL INDEX

GENERAL INDEX.

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